

THE CLIMATE OF A SUGAR BEET STAND

DYNAMICS, IMPACT ON THE CROP AND
POSSIBILITIES OF IMPROVEMENT



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GEOGRAFISKA INSTITUTION
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GÖRAN LOMAN

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THE CLIMATE OF A SUGAR BEET STAND

Dynamics, Impact on the Crop and
Possibilities of Improvement

AKADEMISK AVHANDLING

SOM FÖR AVLÄGGANDE AV FILOSOFIE DOKTORSEXAMEN VID MATEMATISK-NATURVETENSKAPLIGA FAKULTETEN VID UNIVERSITETET I LUND KOMMER ATT OFFENTLIGEN FÖRSVARAS ONSDAGEN DEN 7 MAJ 1985 KL. 10.15 I GEOGRAFISKA INSTITUTIONERNAS FÖRELÄSNINGSSAL, SÖLVEGATAN 13, LUND.

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SAMMANFATTNING During the years 1980-1984, the climatic conditions at a sugar beet stand in southern Sweden were examined. The climatic variables measured most intensely were soil and air temperature, soil moisture, wind velocity and evaporation (potential and actual), but also factors such as precipitation, air humidity, net radiation and heat flux were examined. Most of the readings were made automatically by a 82-channel acquisition system, some variables were, however, measured manually. Both the general microclimate of the stand and the very crop-close conditions in the nearest vicinity of single plants are penetrated. Besides a pure description of the microclimate, the effects on different climatic variables, both by other climatic factors and by the growing stand were quantified. One part of the work examines the climate's effect on the beet growth before emergence and during the establishment. In general, an optimum temperature for sugar beet establishment was achieved. The optimum temperature was dependent on soil moisture. A similar optimum response of the growth was found also in relation to soil moisture content. The effects of the climatic conditions during the establishment and subsequently on the yield at harvest are also treated. Finally, this study examines how soil temperature and soil moisture are affected by different soil characteristics, such as soil moisture, bulk density, aggregate structure and stone content. Here, ways for a deliberate modification of the crop-close climate by using different techniques in soil managment are analysed, in order to improve the conditions for plant development.			
NYCKELORD Microclimate, Agroclimatology, Sugar Beet, Soil Management, Plant Cultivation, Plant Development			
DOKUMENTTITEL OCH UNDERTITEL – SVENSK ÖVERSÄTTNING AV UTLÄNDSK ORIGINALTITEL Klimatet vid ett betbestånd, processer, betydelse för grödan, möjligheter till förbättringar			
TILLÄMPNINGSOMRÅDE Arbetet kan främst användas vid en vidareutveckling av olika former av jordbearbetning och markberedning, för att få information om hur olika ingrepp kan påverka beståndsklimatet			
NYCKELORD Mikroklimat, agroklimatologi, sockerbeta, jordbearbetning, växtodling, plantutveckling			
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P R E F A C E

In 1961 my supervisor Jan O. Mattsson, Ph.D., started the work on his thesis "The temperature climate of potato crops", but even earlier he had made some studies in agroclimatology. Since then the Department of Physical Geography, University of Lund, has had a tradition studying agroclimatological questions and problems. These studies were often made in cooperation with other institutions, such as the Swedish University of Agricultural Sciences, and the former Swedish State Plant Protection Institute, Alnarp. In 1977 the Agricultural Engineering Department at the Swedish Sugar Beet Company made contact with Dr. Mattsson, asking him for help with the establishment of an agroclimatological station at their research field near Lund, and assistance in carrying out the research at this station. The present thesis is based on fieldwork made by the author at this research station, during the years 1980-1984.

Like most doctoral theses, this is not a product of work by only one man. Several people have assisted and encouraged me during different stages of the work. Before I began my studies, the station was established by Jonas Åkerman, Ph.D., who also helped me get started with the field work. The Agricultural Engineering Department and their staff have provided me with great help in the field work; to be mentioned specially are their head agronomist Christer Sperlingsson, the project leaders Åke Wäxt, Harriet Blohmé and Ulf Möller, and Civ.Eng. Per-Olof Eriksson. The acquisition system was constructed by Civ.Eng. Göran Fant, who also taught me about different technical problems when measuring microclimatic variables. The data from the acquisition system was transformed to a more handsome format by Civ.Eng. Vidar Varde at the main office of the Swedish Sugar Beet Company, Malmö. He also performed much of the primary ranking of the data, before the actual statistical evaluations. During the evaluation of the results, I have had great help from my colleagues at the Department of Physical Geography, the head of the department professor Anders Rapp, and from other friends. With B.Sc. Lars Barring I have had many fruitful discussions dealing with climatology in general, as well as with different statistical problems. Professor Reijo Heinonen, at the Department of Soil Sciences, Swedish University of Agricultural Sciences, has provided very valuable commentary on some of the chapters. The language was checked by Susan Brantly, M.A. The photographic work was done by Ulrik Mårtensson, B.Sc.

Of outmost importance is of course the great help I was given by my supervisor, Dr. Jan O. Mattsson.

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I would also thank my wife for her support in my work.

1.1 INTRODUCTION

1.1.1 Climate and Cultivation

Farming, especially plant cropping, is an industry that certainly is dependent on weather and climate. Regional differences in technique used, crop and crop variety reflect differences in the macroclimate. However, due to local factors the climate of single fields situated in the same macro- or mesoclimates can differ greatly. These differences can be even greater than the differences between two nearby macroclimates.

Some factors of importance in forming the local climate of a field are the occurrence of cold air lakes, the distances to larger lakes or the sea, the altitude and the aspect. These factors and others are treated in several studies and presented in many text books. However, our understanding of the exact interaction between these factors is still incomplete.

Also within a field, the climate can vary greatly, reflecting different microclimates. These different microclimates can be caused by natural differences in the soil, such as moisture content or aggregate structure. They can also be caused by the stand itself, as well as by a deliberate modification of the microenvironment through different techniques, like plowing, harrowing, row spacing and plant density.

Micrometeorological and microclimatological studies have examined several single factors dealing with relations between a growing crop and its environment. Often these studies have treated only singular relations, showing how a variable is a function of some other factors, such as the weather, crop structure or soil management.

1.1.2 Sugar Beet Cultivation

In Sweden the sugar beet cropping is concentrated in the southern and southeastern regions. The crop can, however, withstand a fairly wide range of climates. For instance, beets are grown in the Mediterranean area as far south as in Israel, but the crop is also grown in northern Europe, in Finland, close to the arctic circle.

The farmers are well familiar with the fact that the sugar beet during its establishment is fairly sensitive to both climatic stress factors and different attacks by viral infections, bacteria and fungus. Later in the growing season, at least under Swedish conditions, the beet plant can better withstand climatic and other stresses. However, longer periods of dry spells can be troublesome and reduce growth and yield.

At sugar beet cultivation in Sweden, an autumn-plowed and harrowed field, usually in April or May, is seeded with a monogerm seed. The germ is placed at 2-3 cm depth, in rows spaced at 50 cm. Usually, either the field is seeded to a final stand with some 20 cm between each germ, or the field is seeded with some 7 germs/meter. When the later alternative is used, the surplus plants after emergence are removed automatically or manually. Different fertilizers, herbicides, insecticides etc, are used;

this is of course depending on the soil and problems with weeds, insects or other infections.

The harvest is usually done during the months September and October, as late as possible but before the soil is frozen.

As each plant could be treated more or less individually, and as the beet plant is very sensitive to climatic stress during the emergence, great possibilities to improve the yields by different microclimatic modifications are likely.

1.1.3 The Present Study

In 1977, the Engineering Department at the Swedish Sugar Beet Company (SSA/JT) in Staffanstorps, asked the Department of Physical Geography, Lund University, to provide them with help in establishing a climate station at their research area, and to help them in different investigations dealing with climate and beet cultivation.

Under guidance of Jan O. Mattsson, Ph.D., a microclimatological station was established in 1979 by J. Åkerman, Ph.D. From 1980 onward, the studies were carried out by the present author. The results from these studies are presented in this thesis.

The investigations were almost totally financed by SSA/JT, who also assisted in the field work by providing both labor and material.

The aim of the present study has been to do a general survey of factors that form the microclimate of a growing sugar beet stand (*Beta vulgaris*, L). The factors to be investigated most thoroughly were air and soil temperatures, air and soil moisture, evaporation, wind and radiation.

The work could be divided into three parts. One part has been to try to describe the more general microclimate of a growing beet stand, and how this climate is dependent on the interactions between the weather situation and the crop. A minor part of the work, presented in chapter 7, has been to attempt to evaluate if, and how, the microclimate affects the stand's development, from emergence to final yield. The main purpose of this part was to determine whether the microclimate is of importance for the crop and if even smaller differences in the climate affect the growth. The last part has been to examine different ways to deliberately modify the microclimate of a beet stand in order to receive better conditions for the growth, mainly during the early establishment. This part is thoroughly presented in chapter 8.

1.2 THE INVESTIGATION SITE

1.2.1 Geographic Position

The field work was carried out at a research area of the Swedish Sugar Beet Company, Engineering Department (SSA/JT) (Staffanstorps) at Ädelholm. The research area is located some 5 km south of Lund and 3 km north of Staffanstorps, in the southernmost part of Sweden, latitude 55°40' N and longitude 13°12' E (figure 1.1). This research area is located in an arable region, almost completely open and about 25 m a.s.l. The relative relief of the

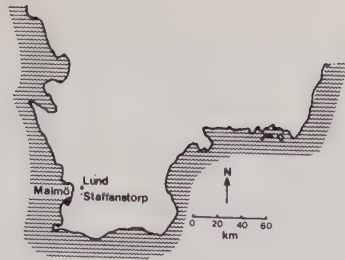


Figure 1.1. Some places mentioned in this study. The research area at Ädelholm is located between Lund and Staffanstorp.

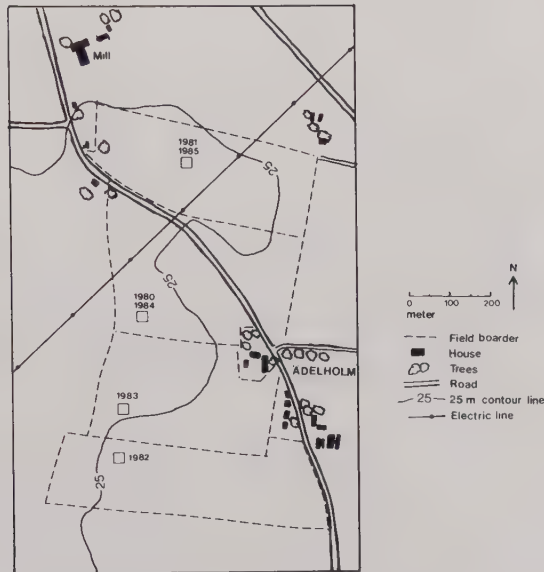


Figure 1.2. The detailed position of the different research fields. The square marks the exact position of the reference surface during the different years.

area is less than 5 m, thus the topography only very slightly affects the local climate. As there are few obstacles like trees or houses in the vicinity of the research area, the area is very suitable for climatic investigations of the present kind.

As crop rotation is used when sugar beets are grown, four different fields were successively used and the climatic station was moved to a new field every year. In figure 1.2 the surroundings of the different fields, as well as the exact position of the climatic station, are shown.

Besides the present studies dealing with climatological questions, several other experiments dealing with different techniques in sugar beet cultivation (different varieties, seeders, herbicides, soil management etc) were made by SSA/JT at the research area. These experiments are currently presented in a yearbook printed in Swedish by SSA/JT.

At the microclimatic station, measurements were made both at a bare reference surface and within beet stands of different structures. Most of these measurements were made by an automatic data acquisition system, more carefully described in the following chapter. The computer and scanner of this system were placed in a hut at the northern end of the bare reference surface. Most of the measurements were made in the vicinity of this hut, usually closer than 50 m. In figure 1.3 is shown an example of the setup at the climatic station and its reference surface.

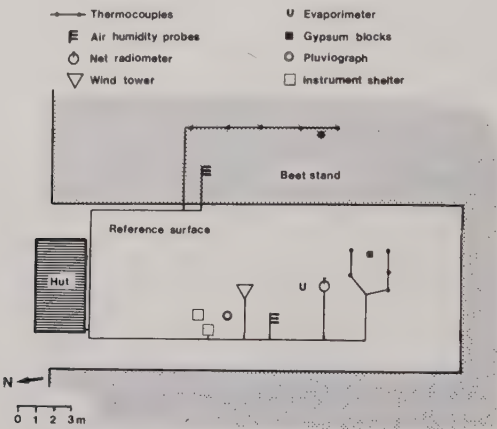


Figure 1.3. The reference plot in 1982 and its set-up.

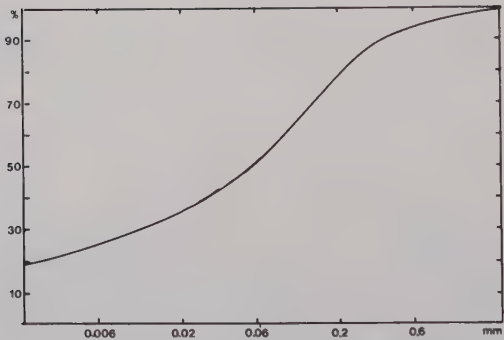


Figure 1.4. The texture of the soil, average of five samples from different parts of the field.

1.2.2 Soil

The soil of the area is a very fertile sandy loam from the Baltic morain. The results of hygrometer and shievering analyses of the soil, made through SSA/JT, are presented in figure 1.4. Analyses have shown that the organic content is roughly 2%, and that the acidity is close to pH 7.0. The absolute water content at PWP (15 bar) is 5.9% and at FC (0.1 bar) 19.4%.

1.2.3 Climate

According to the Köppen classification, this part of Sweden is dominated by a moist, warm temperate climate, with a rather warm summer (Cfb). The climate is greatly affected by the Polar front. The maritime position in the west wind belt generates sufficient precipitation, mainly of frontal type. During the latest normal period (1931-60) the annual mean precipitation was 633 mm and the annual average temperature was +7.8°C. The coldest month was February (-0.8°C), and the warmest was July (+17.4°C). Compare also with the figures 1.5-6, showing the average yearly development of these variables. The potential annual evaporation of the area is about 550 mm (Ångström 1974, p 101).

In figure 1.7 are presented average wind direction frequencies at Sturup airport, nearly 20 km SE of the investigation area. The figure is based on measurements done by the Swedish Meteorological and Hydrological Institute (SMHI) during the years 1972-1980. One can see that the area is dominated by westerly and easterly winds. The general wind velocity at these measurements was 4-5 m/s, being strongest at the beginning of the growing season, and then successively reduced. On average, the easterly and

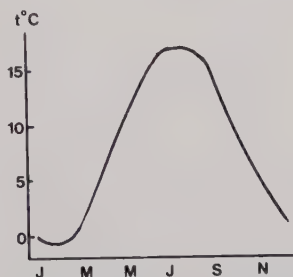


Figure 1.5. Monthly average temperatures for Lund, based on data from the official SYNOP-station during the period 1931-1960.

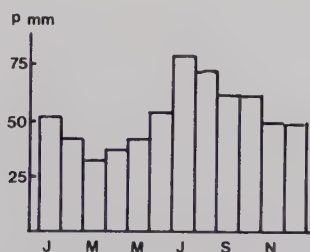


Figure 1.6. Monthly average precipitation for Lund, based on data from the official SYNOP-station during the period 1931-1960.

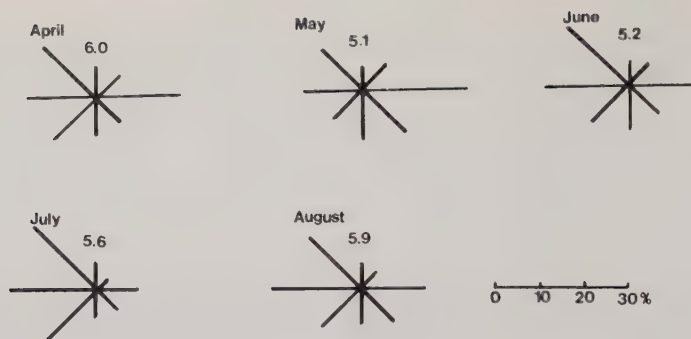


Figure 1.7. Frequencies of wind direction at Sturup, nearly 20 km SE of the investigation area. Based on measurements done by SMHI during the years 1972-1980. The numbers indicate calm occasions.

Table 1.1. Time for sunrise and sunset, at the investigation area on the first and the 15:th each month during the growing season.

Month	Sunrise		Sunset		
	Date	1	15	1	15
April		6:41	6:06	19:42	20:10
May		5:28	5:00	20:42	21:09
June		4:34	4:25	21:36	21:50
July		4:29	4:45	21:52	21:39
August		5:13	5:39	21:13	20:42
September		6:07	6:39	20:00	19:25

westerly winds were somewhat stronger than the winds of other directions.

In table 1.1 is presented the local time for sunset and sunrise at the research area.

On the basis of measurements made between 1961 and 1976, Odin et al (1983) found that the growing season in this part of Sweden begins at the end of March and lasts to the end of November, thus lasting some 240-250 days. In their study presented above, the growing season was defined as the period when the daily mean temperature persistently exceeds +5°C. The threshold value is of great importance. If it is raised from +5 C to +6°C, the theoretical growing season is reduced by 20-25 days (op cit). Furthermore, Odin et al (1983) estimated the temperature sum during the growing season, at +5°C threshold value, to 1700-1800°C.

Table 1.2. Monthly average air temperature (°C) at the official SYNOP-station at Lund, during the field periods.

	April	May	June	July	Aug.
1980	6.0	10.0	15.3	16.4	15.7
1981	5.8	12.8	14.6	16.4	16.2
1982	6.7	11.4	14.8	18.6	17.8
1983	6.3	11.1	15.1	18.5	18.1
1984	7.0	12.0	14.1	16.3	17.6

Table 1.3. Monthly average precipitation (mm) at the official SYNOP-station at Lund, during the field periods.

	April	May	June	July	Aug.
1980	26	21	73	127	85
1981	16	26	76	85	84
1982	26	37	63	25	119
1983	71	95	45	10	24
1984	20	40	108	46	50

1.3 THE WEATHER DURING THE FIELD PERIODS

Here a very brief presentation of the weather during the growing season in 1980-1984 is given.

The temperature was throughout the five years in general quite normal, however, the precipitation showed a greater variation. In table 1.2-1.3 are presented some monthly data of these factors, received from observations done by SMHI at their SYNOP-station in Lund. The following discussion, too, is based on these and other observations, done and presented by SMHI.

Generally in 1980 the temperature was quite normal, except for that the frost situations in April were rather numerous (9 occasions). During the period of establishment, April and May, the weather was drier than normal. On the other hand, June and July were wetter than normal, with some very intensive rain spells.

In 1981, too, April and May were dry. These months were also somewhat warmer than usual. In June this year, more rain fell than usual, but the end of the field period was, as far as concerns the rain, normal.

Throughout the growing season in 1982, the temperature was close to normal. April, to some extent May and certainly July, were drier than usual, but August was much wetter. This year April was somewhat calmer than usual.

The first months of the growing season in 1983 were very wet, which caused a serious delay in the spring farming. July and August were dry this year. The temperature was close to normal during the whole field period.

Initially the growing season in 1984 was somewhat warmer than usual. April and July were dry but in June the precipitation was great. April and August were rather calm, but June was more windy than usual.

In the figures 1.8-1.12 are shown daily values of different meteorological variables during the establishment, the most intense period of investigations, during the years 1982-84. Data are received from measurements done at the investigation area at Ädelholm.

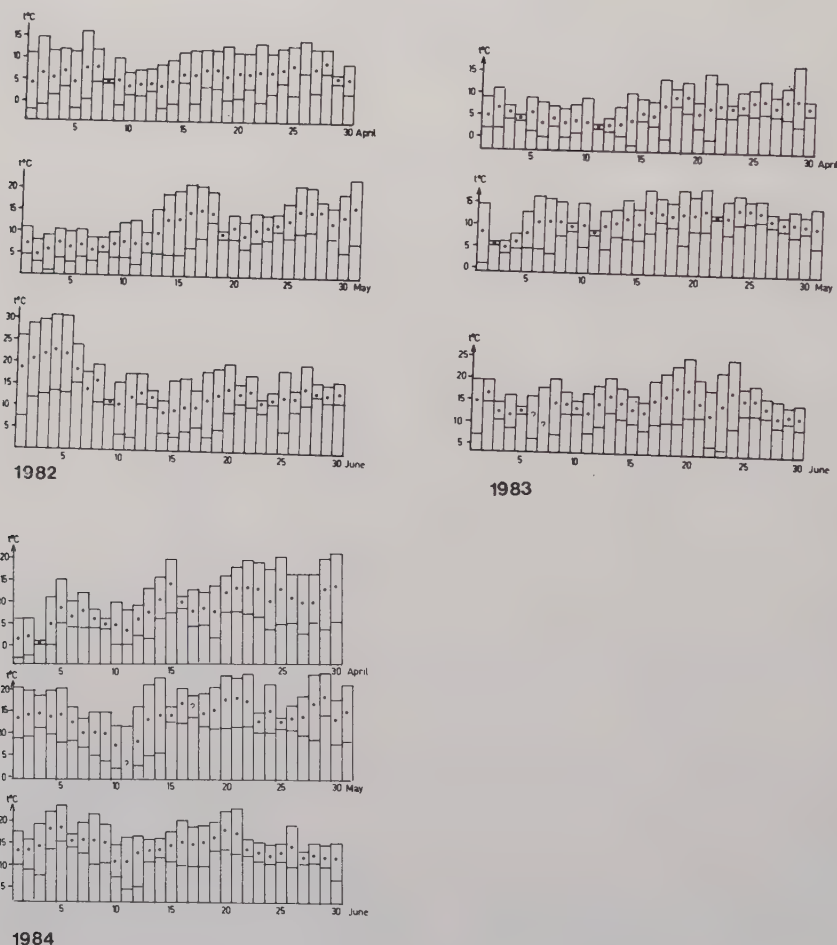


Figure 1.8. Daily mean, maximum and minimum screen temperatures at the reference surface during the months April-June, for the years 1982-84. The values are mainly based on measurements by a Pt100 sensor (presented in chapter 2) but sometimes data from a thermohygrograph were used instead.

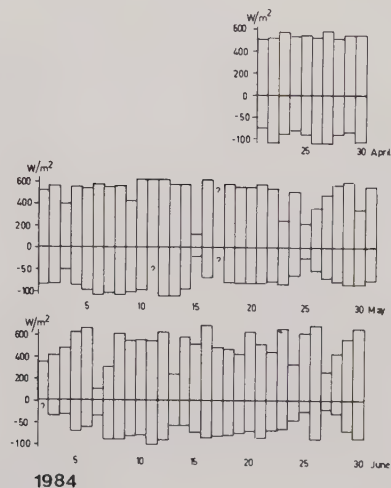
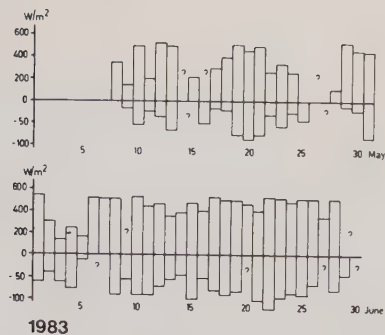
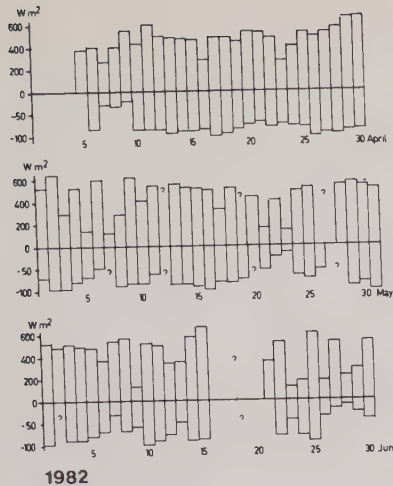


Figure 1.9. Daily maximum outgoing and incoming hourly net radiation, at the reference surface during the months April-June, for the years 1982-84. Note the differences in positive and negative scales.

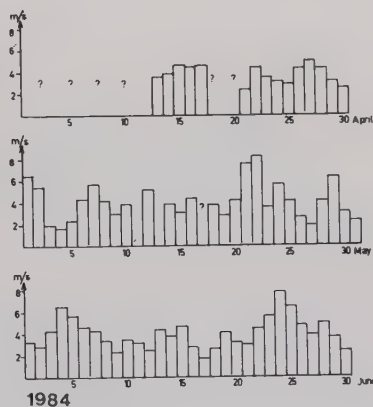
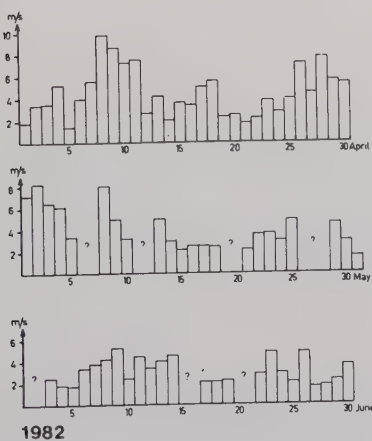
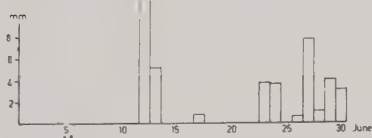
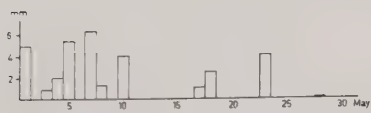
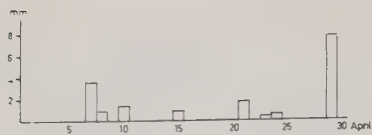
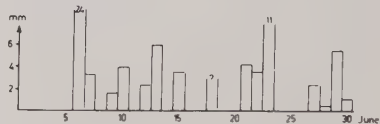
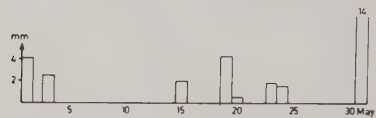
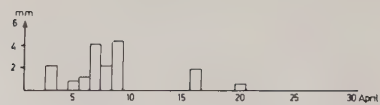


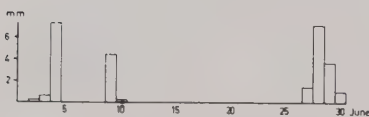
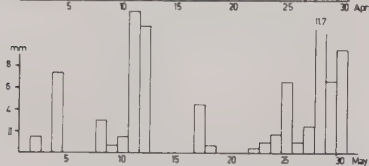
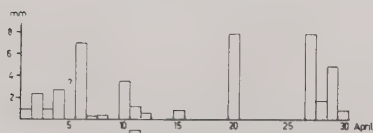
Figure 1.10. Daily mean wind velocity at +5 m at the reference surface during the months April-June, for the years 1982 and 84.



1982



1983



1984

Figure 1.11. Daily amount of precipitation, at the reference surface during the months April-June, for the years 1982-84.

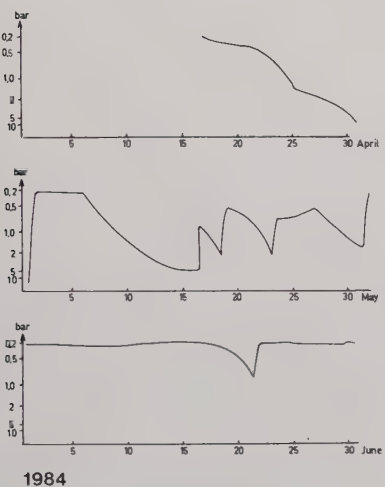
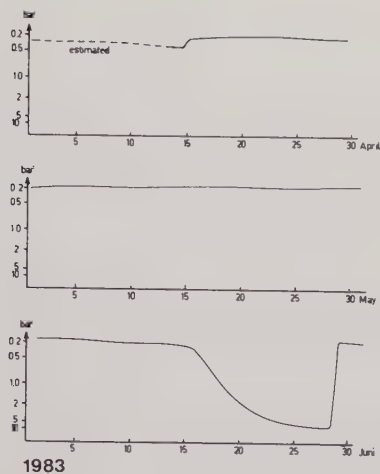
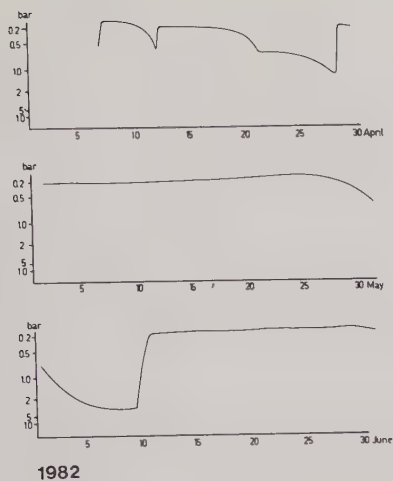


Figure 1.12. Soil moisture content, in bars, at the depth 10 cm, at the reference surface during the months April-June, for the years 1982-84.

2 EQUIPMENT AND GENERAL TECHNIQUE

2.1 INTRODUCTION

In this chapter is given a presentation of the equipment generally used and its principles. To some extent advantages and disadvantages of different methods are discussed. In connection with the separate presentations of the different experiments, a brief overview of the technique then used is given.

At the research area a microclimate station was established based on a 83-channel automatic data acquisition system. In addition to the data recorded automatically, many variables were read manually. The data acquisition system was placed in a heated instrument hut, which from 1983 onward also was equipped with an air conditioner.

The field work was mainly done during the growing seasons in the years 1980-1985. In chapter 1 the weather during these periods are described briefly.

2.2 THE DATA ACQUISITION SYSTEM

The data acquisition system was based on a Heathkit Digital H8 microcomputer and a Schlumberger Serie 3 analogue scanner. The voltmeter used in this system was a Schlumberger Solartron Voltmeter, type 7055, with an input sensitivity of $1 \mu\text{V}$ at the nominal range 10 mV. This voltmeter was calibrated every other year. The limits of error after six months is specified to $0.008\% + 4$ digits.

Logger programs were stored on a standard tape cartridge. Scanning intervals for all channels, 80 analogous and 3 digital, were 5 minutes, and each scanning took about one minute. Hourly means of all channels were displayed on a CRT and a Heathkit H14 line printer. The hourly means were also stored on a Facit paper tape writer, modell 4070. The paper tape was changed every week.

The data acquisition system, which was built by Datafant (Staf-fanstorp, Sweden), did, in general, work well. The most common cause for malfunction was an uneven support of power (220 V AC). These problems were reduced by a Philips voltage stabilizer, and in 1984, when an Endevco battery back-up was installed, this problem was almost totally eliminated. In the summer 1983 there were problems with the paper tape writer and frequently errors were made. Because of this, data from this period initially had to be evaluated manually.

2.3 INSTRUMENTS AND SENSORS

2.3.1 Temperature

Some 50 channels of the data acquisition system were used for temperature measurements with copper-constantan thermocouples.

The soil sensors were made of 0.5 mm thick wires with the terminals melted together. To avoid spurious readings caused by electrolytic effects these terminal junctions were covered with epoxy glue. For the measurements at levels deeper than 10 cm, the leads were placed in brass tubes, 7 mm in diameter. At more

shallow measurements the sensors usually were pushed to the desired level by a thin tube, 3 mm in outer diameter. After the placing this tube was withdrawn. In some experiments the sensors were horizontally pushed to their right positions, and by this, the potential problem of heat conductance through the wires was reduced. However, according to a study by Welterlen & Watschke (1981) the advantage with horizontally mounted sensors is only of lesser importance. Neither in the present study were any significant differences found between horizontally and vertically mounted sensors. Now and then, the soil sensors were picked up and placed in a new spot at the same level. This was made to restrict errors caused by the unrepresentativeness of a single position.

The air temperature sensors were made of 0.25 mm thick wires, which, as above, were melted together. In general, these sensors were sheltered by small aluminium tubes, about 1.5 cm in inner diameter, 4.0 cm long, and black-painted inside.

At measurements of the air temperature very close to a surface, a radiation shield can disturb the environment too much. In measurements of this kind, unsheltered sensors were therefore used. To reduce the radiation error, these sensors were made of only 0.03 mm thick leads which were twisted together. The radiation error, $\Delta\delta$, of these unsheltered sensors is affected by wind velocity and net radiation, and can be estimated by the formula:

$$\Delta\delta = \frac{Q}{\alpha D \pi} \quad 2.1$$

where Q is the radiation effect absorbed by the sensor, α is the heat transfer coefficient and D the diameter of the wire. This formula is thoroughly presented and analysed by Mattsson (1965). In table 2.1 is seen the size of the error in different situations.

When the wires occasionally were lengthened, they were joined by twisting or in 12-way screw connector strips, and shaded from sun radiation by plastic boxes.

In general, the thermocouples were arranged with five sensors in parallel, giving an average temperature of the terminals (Rodskjer 1975). This increased the representativeness of the measurements. Problems with malfunctions of singular sensors are also reduced by using several sensors in parallel.

Table 2.1. Estimated radiation errors (in°C) of the sensors made of 0.03 mm thick wires, at three different radiation intensities and four different wind velocities. Based on formulas presented by Mattsson (1965).

Wind (m/s)	Int. of inc. rad., W/m ²		
	1.2	0.6	0.3
0.01	0.73	0.36	0.18
0.1	0.30	0.15	0.07
1.0	0.12	0.06	0.03
10.0	0.05	0.02	0.01

The temperature of the reference junction was measured by a cuprosnem resistance sensor with a highly linear response to temperature. The function of this sensor was checked yearly and, when needed, it was calibrated. The reference was placed in a styrofoam box 60*60*35 cm in size, with walls 10 cm thick.

According to Telemetric (Arlöv, Sweden), the company which delivered the thermocouple leads, the error of the temperature measurements should be less than 0.3-0.4°C, probably even smaller. As many of the analyses dealt with relative temperatures, the actual error was further reduced.

There are many advantages with thermocouples when measuring temperatures. They are inexpensive, easy to handle and have, if a good voltmeter is used, a high accuracy (Unwin 1980, p 12-13). They can also be made small which is of importance in microclimatic studies.

The reference temperature of the standard level was measured in a white-painted meteorological standard shelter of the kind that is used by the Swedish Meteorological and Hydrological Institute. In this shelter the temperature was measured with three different sensors, a thermocouple made of 0.5 mm thick wires, a Pt100 resistance sensor and a thermohygrograph, Lambrecht 252. Values of the thermohygrograph were frequently compared with an ordinary mercury thermometer and the instrument was justified when needed. The accuracy of the instrument could be estimated to 1-2°C.

The values from the Pt100 sensor were usually used as the reference temperature. When the data acquisition system, for different reasons, was out of order, data from the thermohygrograph were used instead.

2.3.2 Air Humidity

Six channels of the data acquisition system were adapted for air humidity measurements with Vaisala's Humicap humidity probes, modell HMP 14. The principle of these sensors is based on a change in capacity of a thin film, caused by absorption of water. At the range 0-80%, the accuracy is specified to 2%, at the range 80-100%, the accuracy is 3%, the temperature dependence is about 0.5 %RH/°C.

Unfortunately, the calibration of these probes were easily ruined if they came in contact with liquid water. Different herbicides, too, could destroy the electronics of the probes. In order to prevent this the probes were sheltered. In 1980 this shelter was made with a cylinder of thick aluminium foil, 5 cm in diameter and 15 cm long. As this construction sometimes was destroyed by strong winds, the shelters in the next year were made of folded tin, 5 cm in height and 10 cm long. Neither were these shelters sufficient to protect the probes. In the later years, they were therefore made much more sturdy, being plastic tubes 10 cm in diameter and 30 cm long.

From 1981 and onward the absolute water vapor content was calculated on the basis of the relative humidity and the temperature.

As mentioned above, a thermohygrograph was placed in the meteorological shelter. The accuracy of this device was 1.5% and the

range 5-100%. This hygrograph was calibrated yearly. However, data from it were used only rarely.

In some more detailed investigations, the air humidity was measured with Tradoterm's hygrometer DH 100. This sensor, constructed by Philips, is of capacitance type, as well. According to the specification, the range of the meter is 10-95%. These meters were easy to handle. However, a problem was the relatively long response time.

2.3.3 Wind

The wind was measured at three levels by the data acquisition system: 1.75 m, 5.0 m and 10.0 m above the ground. These measurements were made with totalizing cup anemometers manufactured by Teledyn Geotech (modell 1564 B). The accuracy of these anemometers was 1%.

For measurements of wind velocity made close to the surface, two kinds of small, hand held, cup anemometers were used. These were manufactured by Fuess and Datafant (Sweden), respectively. When new, the Fuess meters had an accuracy of some 2%. They had, however, been used in several experiments and the accuracy was therefore greatly reduced. When two or more meters were used simultaneously, they were first compared to each other. By this, the relative error was reduced. These meters currently displayed the so called 'wind way', that is the distance the wind move during a chosen time-unit. From this distance the velocity could be calculated. The Datafant meters could either currently present the wind way, or display the mean wind velocity integrated over 10.3 seconds. When compared to each other these meters gave the same values, and the absolute error could be estimated to less than 5%.

At some studies dealing with wind movements very close to the surface, a hot wire anemometer was used. This meter was manufactured by Lambrecht (modell L 641 N). The probe of this instrument is pencil-thick, and affects the wind flow very little. Two ranges could be used, 0.1-5.0 m/s, and 0.02-0.5 m/s, with accuracies of 0.1 m/s and 0.02 m/s, respectively.

The instrument displayed the instant wind velocity, and this made it difficult to read, especially when the wind did fluctuated. In order to reduce errors caused by this, several readings were made at each position at a certain time interval and the average value was calculated. As the sensor is temperature dependent, comparisons had to be made to the ambient temperature.

2.3.4 Net Radiation

One channel of the data acquisition system measured the net radiation in the middle of the naked reference plot, 1.75 m above the ground. Occassionally, simultaneous measurements at other positions were also made.

The sensors, manufactured by Siemen Ersking (Fredrikshavn, Denmark), were based on a cupper-constantan thermopile. The sensing elements, blackened with optical black lacquer, were protected with semispherical polythene domes. By pumping dry air through

the domes, errors caused by condensed water were reduced. To reduce errors due to deposition of dust on the domes, these were regularly cleared with distilled water. The domes gradually were worn by sand blasting, and on some occasions birds ruined them. When needed these domes were replaced with new ones.

The sensitivity of the sensor is about 0.013 mV/Wm^2 , the exact value being determined at a yearly calibration. The accuracy of the sensor was greatly reduced by its successively changing radiative properties as well as by worn domes. Another problem was the representativeness of the surface above which a single sensor was placed. Finally, the leveling of the sensor could be disturbed which also could affect the precision of the reading. The accuracy when measuring the net radiation under field conditions is discussed by Linacre (1969). It is observed that the errors could be estimated to 5-15%. However, as the net radiation varies greatly, information from readings even with a relatively low accuracy could be of great value.

2.3.5 Heat Flow

Ten channels were used for measuring heat flow, with sensors manufactured by RdF Corp, (New Hampshire). The principle for these sensors is based on the temperature gradient over a thin plate with known heat conductivity, placed in the soil. The gradient, measured by the thermopile, is proportional to the current heat flow in the soil. The plates used had a sensitivity of $0.634 \text{ } \mu\text{V/Wm}^2$.

An advantage with the plate method when determining the heat flux in relation to other techniques that are used, is that the flux is measured directly, without any need for information about the soil thermal properties (Carson & Moses 1963). Furthermore, several plates can be placed at various locations and by this, the representativeness increases. Disadvantages are that the plates can interfere with the heat flow and modify this to a two dimensioned flow (Johannesson 1979). When placed very shallow, at a depth of less than 5 cm, the plates interfere with water movements in the soil. This, too, will reduce the exactness (Fuchs & Tanner 1968). Finally, a poor contact between the plate and the soil will affect the precision (Kimball et al 1976). In order to reduce the errors caused by an unrepresentative position of the plates, the sensors were frequently withdrawn and placed at a new spot.

On the basis of the recorded heat flux and contemporary temperature gradient, heat conductivities of different soils were determined. The accuracy of these determinations will, however, be relatively low since the temperature gradient at these field experiments was not constant. For these determinations, the formula:

$$\lambda = \frac{Q_m}{(dt/dz)} \quad 2.2$$

was used, where λ is the determined heat conductivity at the heat flux (Q_m) and temperature gradient (dt/dz).

2.3.6 Soil Moisture

The soil moisture tension at several depths and positions was measured by hand using gypsum blocks. The sensors (modell 5200) and the instrument (modell 5910) were manufactured by Soil Moisture Corporation (Santa Barbara).

Gypsum blocks have the advantages of being easy to handle and inexpensive. In contrast to pressure tensiometers, they operate over a wide range of tensions (Strangeways 1983). Another important advantage with this method is that it is non-destructive. Thus it is possible to continuously follow a change in soil moisture. A disadvantage is that the change in resistance, besides being affected by soil moisture, is temperature dependent. According to Soil Moisture Corporation this error is 1.5%/°C. However, soil temperatures are normally quite stable and the changes in block reading due to temperature variation result only in small variations in interpretation of soil moisture.

Hanna (1983) pointed out that different porous blocks only give very crude information about the water content and they are very insensitive to changes in soil moisture at the wet end of the scale. Moreover, the sorption and desorption of the blocks is affected by hysteresis (op cit). However, at deeper layers where the soil was denser, the technique used worked very well. When measuring the soil moisture content in the loose top soil, the precision was reduced since the hydrological properties of the blocks were not comparable with these properties of the soil.

In some studies the soil moisture content was determined with gravimetric methods, by which the soil was dried at 105°C in 24 hours. These measurements were also used in order to determine the relation between the absolute soil water content and the soil water tension at different soils.

2.3.7 Evaporation and Precipitation

The potential evaporation was measured with an Andersson's evaporimeter, which is a very simple, but convenient, instrument. The device is made of a small plexiglass tube, 69 mm in diameter and 75 mm high with 48 holes (5 mm in diameter) in two rows at the upper edge. The tank is filled with water and the water level is measured with a micrometer. The instrument is carefully described by Andersson (1969), the designer. Johansson (1969) examines the function of the meter and its dependence on different meteorological factors. Johansson has also compared the results from Andersson's evaporimeter with other techniques to estimate the potential evaporation, and he found it very useful.

During the daily routine, the meter was checked and filled with water. From these readings the average hourly evaporation was calculated. The instrument was very easy to handle and in chapter 4.2 a more detailed analysis of its function is given.

In some studies the actual evaporation was estimated by using a kind of micro-lysimeter. Aluminium boxes, 13*19 cm or 10*13 cm in size and 5 cm deep, filled with soil samples, were placed in the field with their upper edge at ground level. The weight of these soil samples and their water content, was determined during the daily routine, using a scale with an accuracy of 0.01 g. To

reduce errors caused by moving soil particles, four lysimeters were used in each site. If one box gave a diverging value of the evaporation, the result was omitted. A deficiency of the lysimeters used is that the vertical water movement, both in liquid and vapor phase, is interrupted. Especially at precipitation this is a great problem. Therefore estimations of the actual evaporation were not done after a period of rain, even if the input of water was known. After rain, the soil within the boxes was replaced with new, and the dry weight of the soil was determined.

The precipitation was recorded on a paper chart by a pluviograph (Lambrecht 1507). The accuracy could be estimated to 0.1 mm and the time resolution to 15 minutes. The opening area of the pluviograph was 200 cm².

2.4 FIELD WORK, DAILY ROUTINES

During the establishment of the beet stand, from April to June, field observations were made almost daily. Later in the season these observations were made only once or twice a week. Occasionally during some more detailed investigations, also at a later part of the growing season the field work was made at dense intervals.

During these field observations, manual readings of potential evaporation and soil moisture, sometimes also other factors like actual evaporation and total wind way, were made. Notes of the current weather, wind situation and cloudiness were made, as well. The daily routine also included to check the data acquisition system and the sensors, both function and position. When needed the sensors were repaired or replaced.

Phenological observations of the stand and its structure (number of leaves, size of leaves, height and closeness) were made frequently. Observations dealing with emergence and yield were mainly made by the staff of the Sugar Beet Company, who also assisted in the work with the daily routine and with the yearly move of the climate station to a new site.

2.5 DATA EVALUATION

The data from the paper tape writer was transferred every week to a mass storage device at the Main Office of the Swedish Sugar Beet Company, Malmö. The hourly averages of all channels were listed by the Main Office. Other parameters, too, like daily means and extremes and hourly differences between certain channels, were currently listed and used in the later evaluation. Further on, by the Main Office primarily sortings, classifications and calculations of different parameters were made. These listings were later used in the final analyses and evaluations.

The statistical analyses were mainly made on available software programs at Lund University Computing Center (LDC), and on a programmable calculator with a statistic software module (Texas 58C). The most widely used statistic software program at LDC was Minitab, presented by Ryan et al (1981). Finally, a number of specially designed programs for the data evaluation were used. These programs were made both on computers (Zenith Data System,

Z-90 and Z-100) and on the programmable calculator. The statistic theories used for these programs, as well as the statistical evaluation in general, are according to Hammond & McCullagh (1982).

Generally, the 95%-significance level was used, as at a higher significance true relations might also be excluded. Furthermore, the presented levels of significance are purely statistical and does not include the accuracy of the sensors and instruments.

The general time used in the analyses and presented is the Central European time, with no regard to daylight saving time.

3 SOIL AND AIR TEMPERATURES IN GENERAL

3.1 INTRODUCTION

3.1.1 Background

This part of the work has as its aim the description of the general temperature climate close to bare ground and to a beet stand; and the quantification of the effects other climatic variables have on the ground-close temperatures. The subject has been treated by other authors, but often in a descriptive way and with single examples illustrating the conditions and relationships (see Brown 1976, Brown & Rosenberg 1970/71 and Mattsson 1961 and 1966). The present study should be seen both as a complement to these studies, and as background to other experiments presented in this report.

The study will also show the general daily temperature course in the air and in the soil during the period of emergence in April and May. A method for estimating both the daily mean temperature and the temperature at a certain hour is evaluated on the basis of this general development.

3.1.2 Methods

The field measurements were mainly taken during the period of April-August, the two years 1981 and 1982. In some analyses data from measurements during the winter and early spring were also used. The measurements began at the beet stand, in mid May of 1981, and in mid June of 1982.

In 1981, the air temperatures over fallow ground and in and above a beet stand were measured at the levels +10 cm, +50 cm and +175 cm. Soil temperatures were measured at 1 cm, 5 cm, 15 cm and 50 cm under the surface. Under the bare surface, the soil temperature at -100 cm was measured, too. In 1982 air temperatures were measured at the levels +0.5 cm, +10 cm, +25 cm, +50 cm, +100 cm and +175 cm. At the beet stand measurements were also made this year at +40 cm. The subsurface levels in 1982 were the same as in 1981.

The temperature was measured with copper-constantan thermocouples. The air sensors at +0.5 cm were made of 0.03 mm thick wires. These sensors were used unsheltered. The other air sensors were made of 0.25 mm thick wires and sheltered. The soil sensors were all made of 0.5 mm thick wires. At all levels, in the soil as well as in the air, the measurements were made with five sensors in parallel. Other climatic variables examined were net radiation at +1.75 m, wind velocity at +5.0 m, air humidity (relative humidity and vapor pressure) at +100 cm and soil moisture at -10 cm (measured with gypsum blocks). For further information about the equipment used refer to chapter 2.

3.2 DAILY TEMPERATURE COURSE

3.2.1 Theory

Gupta et al (1982) presented a method for predicting the hourly

soil temperature values on the basis of the daily extreme air temperatures. In their method the hourly air temperatures of an investigation site were first estimated from the extreme air temperatures at this site and from the normalized temperature development of a near-by weather station. The received estimates of the air temperature then were used in estimations of the soil temperatures. The normalization was calculated by using the formula:

$$N_i = \frac{T_i - T_{dn}}{T_{dx} - T_{dn}} \quad 3.1$$

where N_i is the normalized hourly temperature at time i , T_i the air temperature of the hour i , T_{dx} the daily maximum temperature and T_{dn} the daily minimum temperature of the actual day. The normalized value for the maximum temperature will thus be 1.00 and corresponding minimum value be 0.00. The monthly averages of these normalized values could be used together with the daily extremes for estimating the daily temperature development either for another year, or, as in the study by Gupta et al, for another site. The estimations of actual temperatures made by the method of Gupta et al were good for the period between the minimum temperature in the morning and the maximum temperature the following afternoon. However, the estimates of the temperature before the daily minimum in the morning are by extrapolation, partly based on the later maximum temperature the same day instead of the proceeding maximum temperature which would have been better. Similarly the estimates of the temperatures after the daily maximum are partly based on the minimum temperature in the proceeding morning. This makes the nighttime estimations much more uncertain.

The study of the daily temperature variation in this section presented, is also based on normalized values of the daily temperature development. However, instead of using the extremes from the same day, the extremes surrounding the temperatures to be normalized were used. In this calculation, the daytime positive extreme was defined as the highest temperature between 11 h and 17 h (T_{cx}), and the nighttime negative extreme the lowest temperature between 23 h and 07 h (T_{cn}). The normalized value (N_{ci}) was calculated by using the formula:

$$N_{ci} = \frac{T_i - T_{cn}}{T_{cx} - T_{cn}} \quad 3.2$$

When normalizing the temperature in the evening the maximum temperature of the same day and the minimum temperature of the coming day was thus used. In this manner all the normalized temperatures in the morning are based on the minimum temperature of the same day and the maximum temperature of the previous day. By this, all normalized values are received from interpolation, which improves the method.

The normalization and estimations were analysed on air temperature data from 1981 and 1982 for +175 cm, and on soil temperatures from the same years at the level -15 cm. For April and May the averages of the normalized values for each hour were calculated and used in the estimations of the temperature for the other year.

3.2.2 Results

In figure 3.1 and table 3.1, the normalized values for April and May in 1982 are presented. It is seen here that the daily temperature development is changed by the longer days, later in the season.

When comparing the normalized values from the different years, no significant differences were obtained. Hence, it is possible to predict the temperature using the method presented. In figure 3.2, the actual daily development of the air and soil temperatures in May 1982, and the estimated temperature development for the same month based on the normalized temperature data from 1981 and the daily extremes in 1982, are shown. The average daily mean air temperature of the month was correctly estimated at $+11.9^{\circ}\text{C}$. The errors of the hourly estimates was usually less than 1.0°C . The similar estimates of the soil temperatures were even more accurate, the hourly error was in these cases always less than 0.5°C .

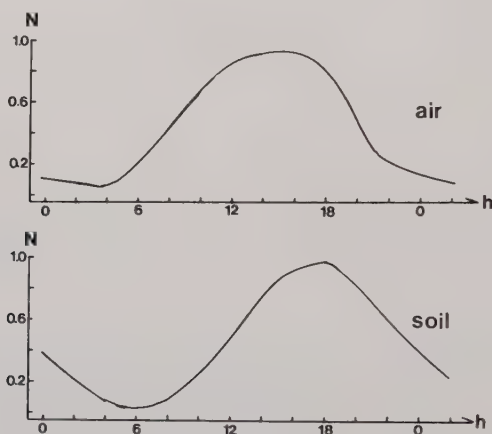


Figure 3.1. Normalized values of the average daily temperature development in May 1982, at the levels $+175\text{ cm}$ (top) and -15 cm (bottom).

It is also possible to use the monthly averages of the normalized values to determine the hourly temperature development of a single day. As the extremes of the monthly averages of the normalized values are not 1.0 and 0.0 respectively (see table 3.1), a transformation must first be done. The estimates of the extreme temperature values will otherwise not be as extreme as the actually measured extreme values. The other estimates, too, will have a similar error. For all values, these transformations were performed using the formula:

$$Nt_i = \frac{N_i - \bar{N}}{t_a} + 0.5 \quad 3.3$$

where Nt_i is the transformed normalized value at the time i , $\bar{N}$ is the mean of the normalized extremes and t_a is the amplitude of the original normalized values. This transformation is further explained in figure 3.3.

Table 3.1. Monthly normalized values for April and May 1982, at the levels +175 cm (air) and -15 cm (soil).

Hour	Air temp.		Soil temp.	
	April	May	April	May
00	0.147	0.130	0.367	0.396
01	0.141	0.092	0.297	0.310
02	0.110	0.067	0.232	0.226
03	0.084	0.063	0.168	0.149
04	0.067	0.070	0.115	0.076
05	0.053	0.132	0.068	0.023
06	0.099	0.236	0.026	0.020
07	0.212	0.345	0.010	0.025
08	0.362	0.463	0.029	0.089
09	0.538	0.589	0.104	0.177
10	0.672	0.684	0.208	0.275
11	0.801	0.748	0.369	0.382
12	0.879	0.800	0.521	0.487
13	0.937	0.873	0.679	0.625
14	0.955	0.890	0.824	0.752
15	0.926	0.915	0.929	0.875
16	0.858	0.902	0.975	0.944
17	0.769	0.889	0.973	0.972
18	0.655	0.803	0.926	0.969
19	0.543	0.631	0.839	0.915
20	0.400	0.435	0.737	0.825
21	0.300	0.294	0.631	0.715
22	0.211	0.237	0.535	0.599
23	0.189	0.194	0.446	0.494

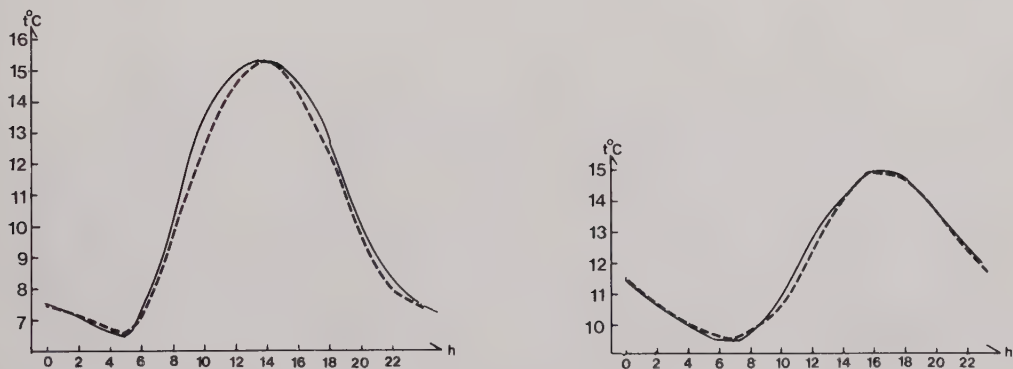


Figure 3.2. The estimated daily development in May 1982 (broken line) and the actual development (solid line), of the air temperature at +175 cm (left) and the soil temperature at -15 cm (right).

These estimations were tested on April and May 1981; the average error of a single hourly estimate of the air temperature was 1.2°C (± 0.3), at the 95% significance. As above, the estimates of the soil temperatures were still lower. The errors were mainly due to one of two factors. A sudden change in the cloud cover could cause an anomaly in the temperature development between two extremes; which was not noticed in the estimations (figure 3.4).

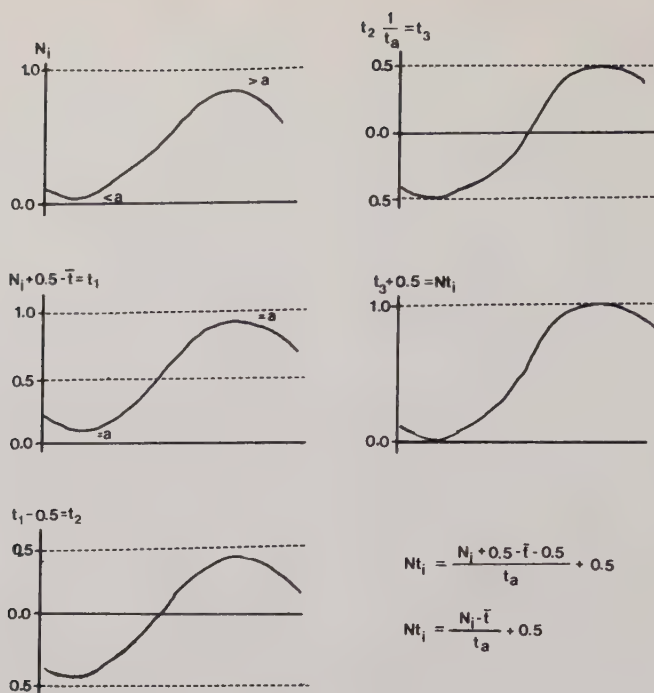


Figure 3.3. Explanation in five steps of the transformation presented in the formula 3.3. N_i is the original normalized value, received by the formula 3.2, $\bar{t}$ is the mean of the normalized extremes, t_a is the amplitude of the original normalized values, and a the mean of the difference between the original normalized extremes and the desired extremes (0.00 or 1.00).

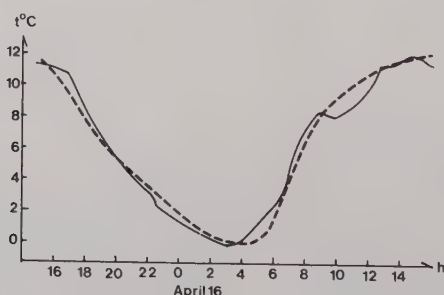


Figure 3.4. Illustration of errors in the air temperature estimate caused by sudden changes in the cloud cover. The estimate is shown by the broken line, the actual temperature by the solid line. Data from 1982.

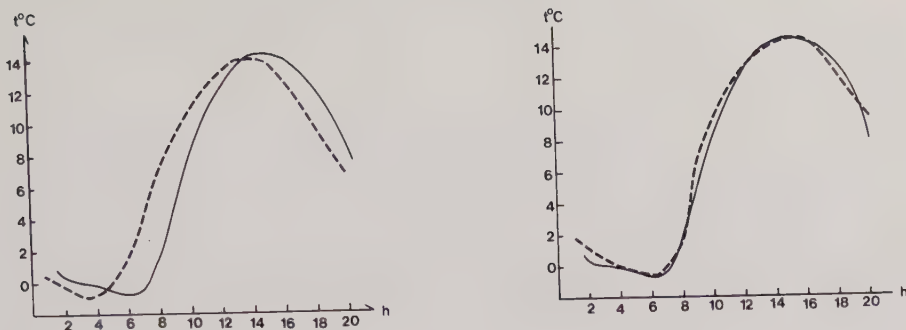


Figure 3.5. To the left is presented the actual air temperature development in April 2, 1982 (solid line) and the estimated (broken line). To the right is presented the actual temperature the same day and an estimation after time correction according to the formula 3.4.

There was also a notable error if the actual extreme temperatures did not appear at the time of the normalized extreme (figure 3.5). However, if it is known at what time the actual extremes did appear, it is possible to make corrections for this kind of error. These corrections were made by modifying the time scale by using the equation:

$$t_o = X_1 + \frac{X_1 - X_2}{\hat{X}_1 - \hat{X}_2} * (\hat{t} - \hat{X}_1) \quad 3.4$$

where t_o is the corrected time for an estimate to appear; $\hat{t}$ is the original time for an estimate according to the normalized development; $\hat{X}_1 - \hat{X}_2$ is the number of hours between the original estimates of extremes; $X_1 - X_2$ is the number of hours between the actual extremes; $\hat{X}_1$ and $\hat{X}_2$ are the times of the original estimates of the previous extremes; X_1 and X_2 are the actual times of the extremes (figure 3.6).

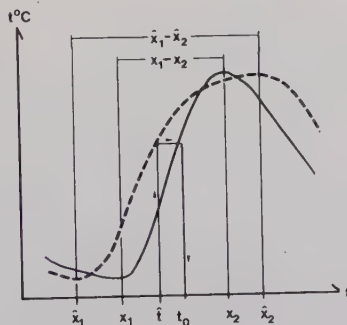


Figure 3.6. Explanation of the constants in the formula 3.4. The solid line is the actual temperature, and the broken line the estimated temperature before any transformations in time.

After such a transformation in time, the average errors of the hourly estimates were reduced to 0.9°C (± 0.2). However, in practice this correction is seldom possible to make; if the time of the daily extremes are known, usually all the hourly values are known, too.

It is of course possible to make estimates of a single day's mean temperatures. When testing this in May 1981 the average error was 0.3°C (± 0.2). This could be compared with a method used by SMHI (the Swedish Meteorological and Hydrological Institute), which is based on the temperatures at 7 h, 13 h and 19 h, and the daily minimum temperature (Eriksson 1980). For the same period the "SMHI-method" showed an average error of 0.2°C (± 0.2). Another widely used value for an estimated daily mean temperature is the mean of the daily extreme temperatures. In May 1981 the average error from this method was 0.4°C (± 0.2).

3.2.3 Conclusions

By using the normalized daily temperature development and the daily extreme temperatures, it was possible to make a very good estimate of the monthly average of the daily temperature development and the daily mean temperature. It was also possible to make good estimates of the average development during a shorter period, like a week. The estimates of both temperature development and daily mean temperature for just a single day were in general also good, especially if no greater changes in weather or cloud cover had occurred.

3.3 THE TEMPERATURE CLOSE TO THE GROUND

In the figures 3.7-3.21 the results from some of the measurements made in 1982 describing the temperature variation close to the ground are presented. Some of the recorded vertical temperature gradients, both in the soil and in the air, are presented in tables 3.2 and 3.3.

3.3.1 Air Temperature over Fallow Ground

The temperature of the air closest to the surface usually showed, in relation to the temperature at +175 cm, a positive anomaly between 11 h and 16 h (figures 3.7-3.9, and table 3.2). No greater differences were found for the different months, and in general, the difference in daytime at +10 cm was between 2°C and 3°C . On cloudless days this anomaly was stronger, of some $4-5^{\circ}\text{C}$ (compare figures 3.8 and 3.10), and occasionally at single observations it could be much higher, over 10°C (figure 3.11). The recorded differences between cloudy and cloudless days could not be verified by a student's t-test, probably because of the limited material on which the analysis was based. One must also consider that the wind velocity affects the vertical gradient, and this variable, can in spite of a high radiation, repress the development of the gradient. From the figures one can see that the gradient was sharply increased closer to the ground.

The strongest negative anomaly in relation to the temperature at +175 cm in nighttime, was found at +25 cm. At the height of the summer, this vertical minimum was very short in time and notic-

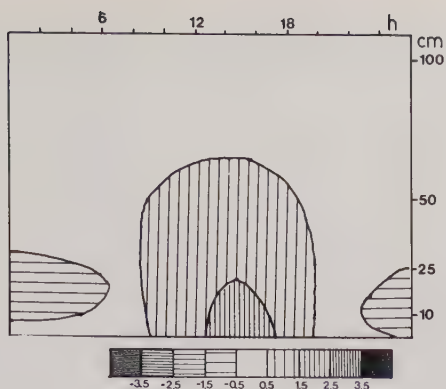


Figure 3.7. Average daily variation of air temperature, in relation to the temperature at 175 cm, above fallow ground. Based on data from April 1982.

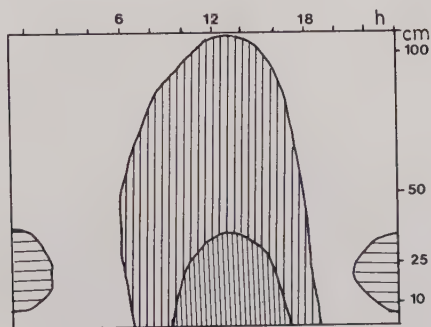


Figure 3.8. Average daily variation of air temperature, in relation to the temperature at 175 cm, above fallow ground. Based on data from June 1982.

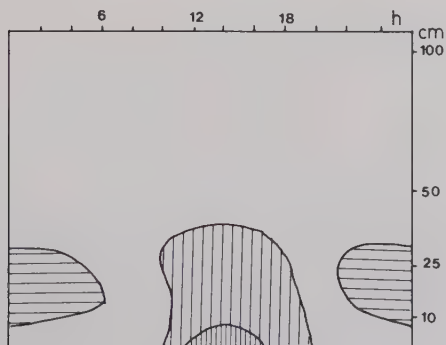


Figure 3.9. Average daily variation of air temperature, in relation to the temperature at 175 cm, above fallow ground. Based on data from August 1982.

Table 3.2. Temperature differences, in °C, between different heights, over fallow ground and over the beet stand. The 95% confidence limits are also marked.

		April	May	June	July	August
Fallow ground						
13 h						
10-175 cm	1981	2.5+/-0.4	2.8+/-0.4	1.5+/-0.3	1.8+/-0.4	2.2+/-0.6
	1982	1.4+/-0.4	-	2.6+/-0.9	1.1+/-1.6	0.9+/-0.5
01 h						
10-175 cm	1981	-0.4+/-0.2	-0.3+/-0.2	-0.2+/-0.2	-0.0+/-0.1	-0.3+/-0.3
	1982	-0.2+/-0.9	-1.2+/-1.3	-0.2+/-0.6	-0.2+/-0.9	-0.5+/-0.2
Beet stand						
13 h						
10-175 cm	1981	-	2.1+/-0.4	4.5+/-0.6	2.2+/-0.6	0.6+/-0.7
	1982	-	-	3.5+/-1.0	3.2+/-0.5	2.1+/-0.8
25-175 cm	1981	-	-	-	-	-
	1982	-	-	1.2+/-0.7	1.4+/-0.3	1.1+/-0.3
01 h						
10-175 cm	1981	-	-0.3+/-0.2	-0.2+/-0.2	-0.0+/-0.1	0.3+/-0.3
	1982	-	-	-1.7+/-2.2	-0.6+/-0.2	-0.4+/-0.4
25-175 cm	1981	-	-	-	-	-
	1982	-	-	-1.7+/-0.4	-0.5+/-0.2	-0.6+/-0.7

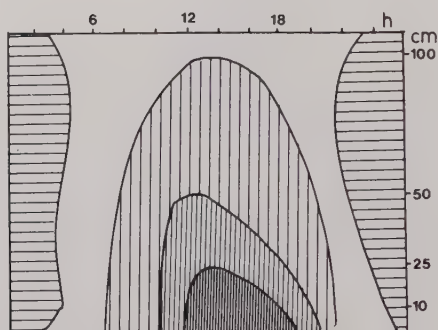


Figure 3.10. Average daily variation of air temperature, in relation to the temperature at 175 cm, above fallow ground during cloudless conditions in June 1982. Compare with figure 3.8.

able only between 1 h and 2 h. Earlier and later in the year, this minimum lasted longer, and was noticed between 22 h and 04 h. A plausible reason for this is that the night is the shortest during the height of the summer. However, the differences between the months are, as seen in the tables, not statistically significant.

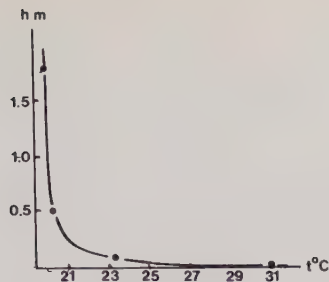


Figure 3.11. Vertical temperature gradient, recorded in a single measurement in July 9, 1985 at 9.55. The net radiation was at this occasion 508 W/m^2 and the wind velocity 2.1 m/s .

3.3.2 Air Temperature at a Beet Stand

Here too, the temperature differences were examined between the standard height $+175 \text{ cm}$ and the lower levels.

During the daytime in June, a positive surface-close gradient developed at the beet stand (figure 3.12). This anomaly reached its maximum in the early afternoon, 10 cm above the ground. In 1981 the anomaly at 13 h was 4.5°C (± 0.8) and in 1982 it was 3.5°C (± 1.0). The fact that the maximal gradient was found at $+10 \text{ cm}$ and not at the most surface-close level, is due to the uplift of the boundary layer, caused by the beet stand. The maximal anomaly of the later months was found at $+10 \text{ cm}$, too, but the anomaly is now weaker. In July and August 1981 at 13 h it was 2.2°C (± 0.6), and 0.6°C (± 0.7), respectively. Corresponding values for 1982 are 3.2°C (± 0.5) and 2.1°C (± 0.8) (figures 3.13 and 3.14). If one only consider the cloudless situations, the received result will be of the same kind, only more extreme.

In the figures is indicated that the greatest gradient appeared later in the day at the most surface-close layer than at higher levels. In July and August, for both years, at the surface-close level $+0.5 \text{ cm}$, this maximum anomaly appeared at noon; 10 cm above the surface it appeared at 10 h ; and at $+25 \text{ cm}$ still earlier, between 8 h and 9 h . The reason for the later maximum at the lower levels could be that these levels to a great extent are shaded by the crop during the early hours of the day. Another reason for this could be the rising evaporation during the day. This will cool the climate within the stand and by this repress the otherwise high positive temperature anomalies during mid-day.

Mattsson (1961) describes a much more distinct layer of a maximum gradient at the top of a beet stand. The reason why this was not noticed here could be that the present study is based on averages of data from a longer period including different kinds of weather conditions. Thus, a study of a single occasion gives a more distinct layer of extreme positive anomaly.

In 1981 the greatest negative anomaly at nighttime, in relation to the temperature at $+175 \text{ cm}$, was found in June at the layer between $+25 \text{ cm}$ and $+10 \text{ cm}$. At 1 h this anomaly was at $+25 \text{ cm}$ -1.7°C (± 0.4). In 1981 this level was not examined; instead, the more surface-close layer at $+10 \text{ cm}$ was found to be the coolest. This nighttime maximal anomaly at $+25 \text{ cm}$ was repressed by the growing stand, in July it was -0.5°C (± 0.2) and in August -0.6°C (± 0.4).

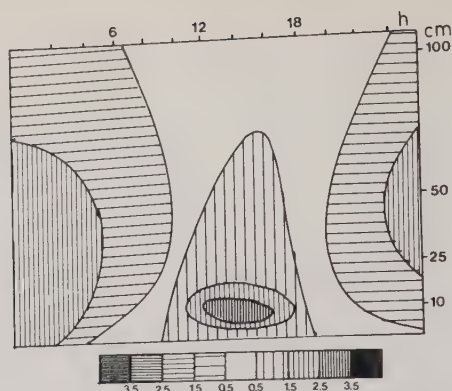


Figure 3.12. Average daily variation of air temperature, in relation to the temperature at 175 cm, above the beet stand. Based on data from June 1982.

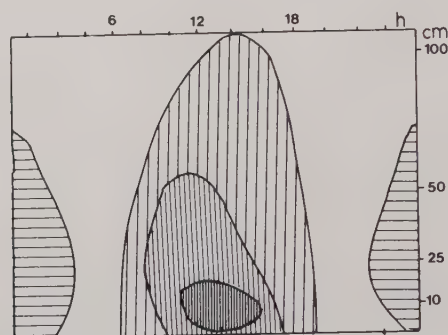


Figure 3.13. Average daily variation of air temperature, in relation to the temperature at 175 cm, above the beet stand. Based on data from July 1982.

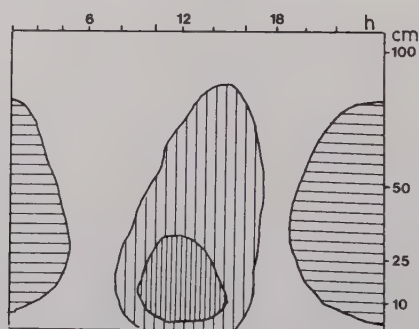


Figure 3.14. Average daily variation of air temperature, in relation to the temperature at 175 cm, above the beet stand. Based on data from August 1982.

No greater differences were found when analysing only cloudless conditions; compare figures 3.15 and 3.13. The reason for this is probably the same as for the bare ground, that is, the great deviation in the limited material.

The differences in temperature between the active layer and the layer at +175 cm, are repressed by the growing stand. This can be explained by many factors. One is that the positive anomaly was successively repressed by the cooling evaporation from the stand. Another is that the active layer of a beet stand, becomes more and more diffuse during growth, with single larger leaves emerging high above the average plant height. This will enlarge the active layer and thus by diluting effects, decrease the maximum differences. Mattsson (1966) achieved results supporting this theory when comparing the nighttime temperatures of two potato crops with different densities. In the more dense stand the anomaly was higher, but the vertical extension of this anomaly was lower. Still another effect of this uneven top surface of the stand is the increased wind turbulence. This, too, will repress the maximum temperature anomaly, but increase the thickness of the layer showing this anomaly.

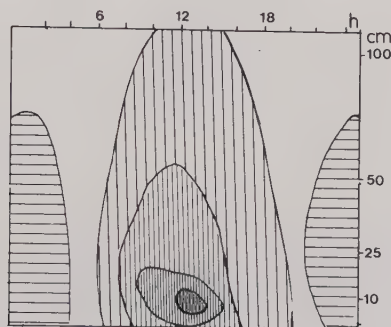


Figure 3.15. Average daily variation of air temperature, in relation to the temperature at 175 cm, above the beet stand during cloudless conditions in July 1982.

3.3.3 Soil Temperature under Fallow Ground

3.3.3.1 Vertical gradient

The soil temperatures at different levels were in general analysed in relation to the soil temperature at -50 cm.

An overview of the results is presented in table 3.3 and figures 3.16-3.19. The greatest negative gradient in the soil between -50 cm and -5 cm developed in May, with a maximum at 16 h. In 1981 this gradient was in general -6.2°C/m (± 2.6) and in 1982 -10.2°C/m (± 2.5). During cloudless conditions in 1982 this gradient was still steeper, -15.5°C/m (± 1.0) (compare figures 3.19 and 3.17). In 1981 the cloudless conditions were too few for receiving any adequate result. This can also explain why the gradient in 1981, on an average, was weaker. Corresponding values for August were -5.0°C/m (± 2.0) (1981), and -7.0°C/m (± 3.4) (1982).

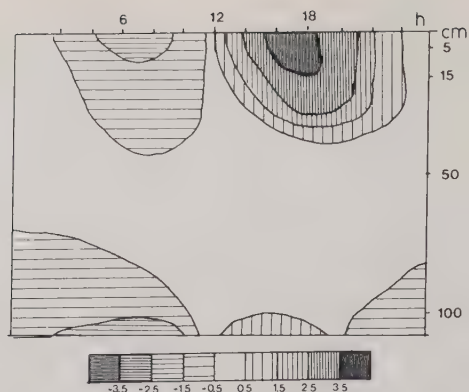


Figure 3.16. Average daily variation of soil temperature, in relation to the temperature at 50 cm, under fallow ground. Based on data from April 1982.

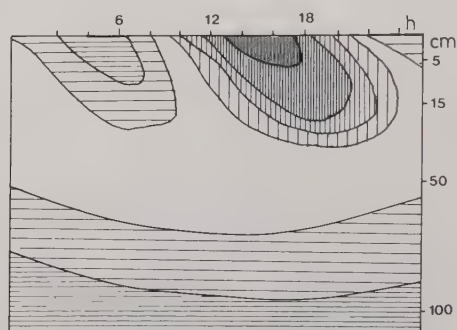


Figure 3.17. Average daily variation of soil temperature, in relation to the temperature at 50 cm, under fallow ground. Based on data from June 1982.

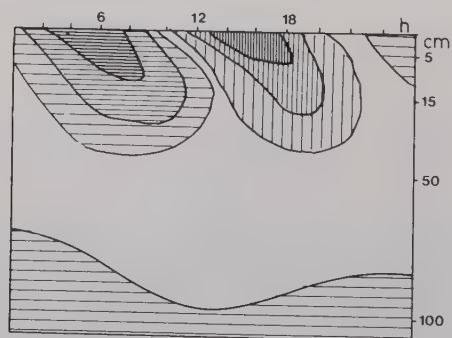


Figure 3.18. Average daily variation of soil temperature, in relation to the temperature at 50 cm, under fallow ground. Based on data from August 1982.

The nighttime difference between the levels -5 cm and -50 cm was greatest at the end of the measuring period in August. The gradient is increased by a high temperature at deeper layers and a low one at the surface layers. This condition appears because of the thermal inertia of the soil in the latter part of the growing season, when the surface has begun to cool but the deeper layers still are warm.

In figures 3.16-3.18 one can see how the energy during daytime was conducted in a pulse to deeper layers. At about 14 h, the surface temperature reaches its absolute maximum. After that time the surface was cooled, by evaporative, convective and radiative energy losses to the atmosphere, and by heat flux, conduction, to deeper layers. The latter process, which is rather slow warms the deeper layers, giving them a delayed maximum temperature.

The thermal gradients for both years, during April-August (except from some afternoon hours in April) were always negative in the deeper layer, between -50 cm and -100 cm. This negative gradient was the weakest in August at noon.

At this deeper layer the maximum gradient was reached first in July. This month it was at 4 h $-4.4^{\circ}\text{C}/\text{m}$ (± 0.9) (1981) and $-6.0^{\circ}\text{C}/\text{m}$ (± 1.8) (1982). In contrast to the top 50 cm of the soil profile, in all the five months the gradient of the deeper layer numerically was the weakest in daytime, at noon. Because of the very low daily variation, the time for this minimum gradient could not be verified statistically.

Table 3.3. Temperature differences, in $^{\circ}\text{C}$, between different depths, under fallow ground and under the beet stand. The 95% confidence limits are also marked.

		April	May	June	July	August
Fallow ground						
15 h						
50-5 cm	1981	-4.1 $\pm$ 3.0	-3.0 $\pm$ 1.3	-3.5 $\pm$ 2.1	-3.0 $\pm$ 0.4	-3.0 $\pm$ 0.6
	1982	-4.2 $\pm$ 0.8	-4.3 $\pm$ 1.1	-2.9 $\pm$ 1.6	-2.5 $\pm$ 0.8	-2.6 $\pm$ 1.0
100-50 cm	1981	-0.5 $\pm$ 0.4	-2.0 $\pm$ 0.6	-1.5 $\pm$ 0.9	-1.7 $\pm$ 0.4	-1.1 $\pm$ 0.7
	1982	0.4 $\pm$ 1.0	-1.6 $\pm$ 0.8	-1.7 $\pm$ 0.6	-2.3 $\pm$ 1.1	-0.6 $\pm$ 0.6
05 h						
50-5 cm	1981	3.7 $\pm$ 0.9	2.3 $\pm$ 0.5	1.9 $\pm$ 0.5	2.4 $\pm$ 0.3	3.3 $\pm$ 1.0
	1982	1.7 $\pm$ 0.4	1.0 $\pm$ 0.4	1.6 $\pm$ 0.7	1.4 $\pm$ 0.4	1.6 $\pm$ 0.5
100-50 cm	1981	-1.0 $\pm$ 0.4	-2.4 $\pm$ 0.6	-1.8 $\pm$ 0.3	-2.2 $\pm$ 0.5	-1.5 $\pm$ 0.7
	1982	-1.6 $\pm$ 0.6	-1.6 $\pm$ 0.5	-1.9 $\pm$ 0.7	-2.9 $\pm$ 0.7	-0.6 $\pm$ 0.8
Beet stand						
15 h						
50-5 cm	1981	-	-5.0 $\pm$ 3.1	-3.4 $\pm$ 0.8	-2.5 $\pm$ 1.6	-2.2 $\pm$ 1.3
	1982	-	-	-3.6 $\pm$ 1.1	-2.8 $\pm$ 0.7	-2.6 $\pm$ 1.8
05 h						
50-5 cm	1981					
	1982		2.9 $\pm$ 0.8	1.6 $\pm$ 0.5	1.0 $\pm$ 0.4	1.6 $\pm$ 1.1
		-	-	1.3 $\pm$ 1.2	1.3 $\pm$ 0.8	2.3 $\pm$ 1.8

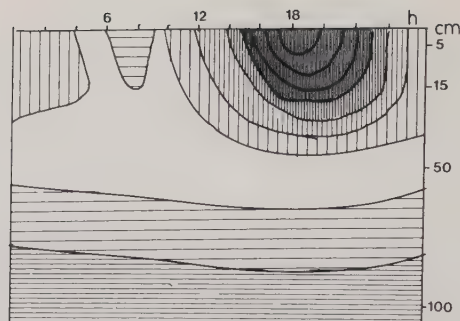


Figure 3.19. Average daily variation of soil temperature, in relation to the temperature at 50 cm, under fallow ground during cloudless conditions in June 1982.

The maximum gradient occurring early in the season at the surface-close layer is a consequence of the delayed temperature raise of the deeper soil layers. In May-June the general heat gain also had reached the level 50 cm below the surface, which dampened the further increase of the thermal gradient above this level. After still another month the heating reached the deeper layer between -50 cm and -100 cm. First in July-August a stronger relative temperature rise in the soil was noticeable at the depth of one meter, which dampened the gradient.

In figure 3.20, the result of measurements describing the yearly development of the vertical daily mean temperature gradient is presented. The figure is based on measurements from the period November 1981-September 1982. One can see that in late February-April and in mid August the mean temperatures were constant through the whole profile, and that the level at -5 cm, in comparison with the deepest level at -100 cm, reached the strongest positive anomaly in July. During the months not examined, September-November, this anomaly for certain was negative. The recorded negative anomaly in the winter was not as strong as the positive one in the summer. This was probably caused by the insulating effect of the snow cover. In January the snow layer was approximately decimeter thick. In Ultuna, Sweden ($59^{\circ}49'N$; $17^{\circ}39'E$), Rodskjer & Tuvevsson (1976) noticed in a similar study concerning the monthly mean temperatures at the depths of 5 cm and 50 cm, that the maximum positive gradient appears in June and the maximum negative in November.

3.3.3.2 Daily Soil Temperature Amplitude

The daily amplitude at different levels was analysed during the period April-August, 1981 and 1982. The examined levels were -15 cm and -50 cm. Air temperature at +175 cm was used as a reference. In these analyses, the average daily amplitudes for the first and last half of the different months were examined. The results are presented in figure 3.21. A factor analysis has verified that the daily amplitude at -50 cm did increase during the summer. The change at -15 cm is more uncertain. The amplitude

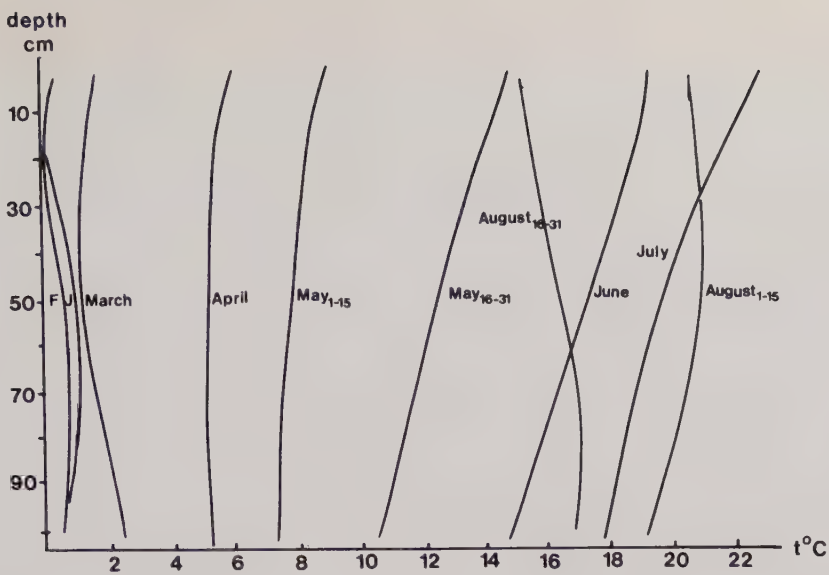


Figure 3.20. Two weeks' average daily vertical temperature profile in the top layer of soil, without any vegetation cover. For all months, except May and August, only the first two weeks are presented.

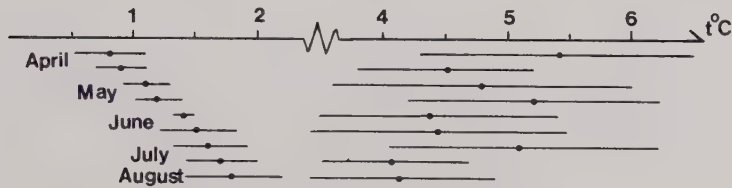


Figure 3.21. Average daily mean temperature amplitudes for the first and last half of each month, at the two depths 50 cm (left) and 15 cm (right) under the surface. The 99 % confidence limits are marked. Based on data from 1981 and 1982.

at this level seems to decrease during the summer, but this is not statistically verified. The lack of statistical significance could be due to the greater variation of this surface-close temperature. There is also a good correlation between the amplitude at -15 cm and the contemporary amplitude in the air (the correlation coefficient, r , is 0.66 (+/-0.08). Corresponding correlation for the deeper layer was weaker ($r=0.20$ +/-0.13).

A chi-two test showed, at the 95% level of confidence, that there was a correlation between the amplitude at -15 cm and the contemporary soil moisture content at -10 cm, where an increase in soil moisture decreased the amplitude. This correlation was not found for the deeper layer.

The differences in the yearly development of the amplitude at the two levels can be caused by a raised heat conductivity of the soil during the summer. The increased heat conductivity raises both the daytime heat flux from the surface to deeper layers and the nighttime flux from deeper layers to the surface. Thus will the amplitude be increased at deeper layers and decreased at more shallow layers. An increase in conductivity can be caused by an enlarged compaction of the bare soil during the summer, described by, among others, Eriksson et al (1974). This compaction is of course most intense in the surface-close layer, which has been loosened by plowing and harrowing. However, it will also be noticed in a deeper layer, which during the winter was loosened by different frost processes. Changes in the heat capacity, too, could cause changes in the amplitude. An increased content of soil water causes a higher heat capacity, which in turn will dampen the amplitude (consult Oke 1978, p 40). This can be the reason for the observed correlation between soil moisture and daily temperature amplitude at the surface close level. Besides the effect of the water on the heat conductivity of the soil, this correlation can also be a result of an evaporative cooling, which is most intense in daytime in a wet soil.

3.3.4 Soil Temperature under a Beet Stand

The soil temperature under a beet stand was only examined in the top layer, down to the depth of 50 cm.

The conditions under the beet stand corresponded well to those under the bare ground. Furthermore, a numerical reduction of the vertical gradient by the growing stand could be traced, with the highest gradient in May. However, this change could not be verified statistically, probably because of the great variation in the material. See figure 3.22 and table 3.3. This development is caused by the insulating effect of the stand.

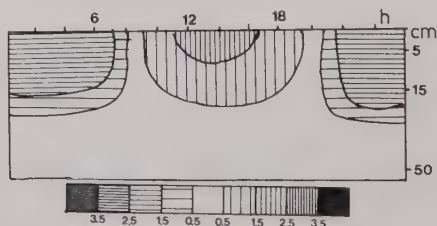


Figure 3.22. Average daily variation of soil temperature, in relation to the temperature at 50 cm, under the beet stand during cloudless conditions in August 1982. Compare with figure 3.17.

3.3.5 Conclusions

Over the fallow ground, in daytime a positive surface close temperature gradient was found and at nighttime a negative gradient. Above the beet stand, an active layer, successively uplifted by the growing crop was noticed. These conditions are well known from the literature. No greater effects of the cloudiness on this pattern were in general noticed. However, if a condition with a thick cloud cover was picked out and compared with a cloudless condition, the differences were evident, with a stronger gradient at cloud-free conditions.

In the top 50 cm of the soil in daytime, a negative anomaly and at nighttime a positive anomaly was developed; These anomalies were strengthened in cloudless conditions. The gradient of the deeper layers was always negative during the vegetation period. At the surface, the daytime temperature amplitude was strongly correlated to the temperature amplitude of the air. This correlation was weaker for the deeper layer, -50 cm. In the deeper layer the daily amplitude increased during the growing season. At the surface layer, the amplitude decreased during the summer. In all likelihood this was due to the changes in heat conductivity.

The daily average soil temperatures were constant through the whole vertical profile in mid-August and in February-April; but negative, with lower temperatures at more shallow layers, in the spring and positive in the autumn.

3.4 EFFECTS OF THE WEATHER ON THE TEMPERATURE CLOSE TO THE GROUND

These studies analysed how different weather conditions affected the vertical temperature gradient, both above and under the ground surface. The analyses of air temperatures dealt with the gradient over fallow ground between +175 cm and +10 cm, daytime at 15 h and nighttime at 3 h. The analyses of the subsurface conditions mainly dealt with the gradient between -5 cm and -15 cm, but in some occasions, also the gradient between -5 cm and -50 cm was examined. The subsurface studies, too, dealt with two situations per day, in 1981 at 3 h and at 15 h, and in 1982 at 4 h and at 16 h. The analyses are based on measurements made during the periods 81.05.07-08.28 and 82.06.01-08.26.

The studies have also evaluated how different weather conditions, together with the growing beet stand, affect the surface-close temperature climate at +10 cm and at -5 cm. In these studies, data contemporary with data presented in the studies on fallow ground were used, with the exception that the period in 1982 did not begin until June 22.

The examined weather elements were contemporary air temperatures and net radiation at +1.75 m, relative humidity and vapor pressure at +1.0 m, wind velocity at +5.0 m, and soil moisture at -10 cm. A weighted value of the net radiation (Q_{s_w}) also was used, based on both the contemporary radiation and the radiation during the previous hours, calculated according to the formula 3.5. In this formula Q_{s_0} stands for the contemporary value of net radiation and $Q_{s_{-1}}-Q_{s_{-3}}$, for the values the three previous hours.

$$Q_{s_w} = \frac{4*Q_{s_0} + 3*Q_{s_{-1}} + 2*Q_{s_{-2}} + Q_{s_{-3}}}{10} \quad 3.5$$

3.4.1 Air Temperature Gradient Above Fallow Ground

3.4.1.1 Daytime

Generally, the daytime air temperature was higher close to the ground than at the level +1.75 m. Constants describing the recorded correlations between this gradient and other meteorological variables are presented in table 3.4. From the table one can see that net radiation, air temperature and vapor pressure in both years were linked to this gradient. A chi-two analysis has verified, at a 99% significance, that the relative humidity, too, was negatively correlated to this gradient.

The net radiation, especially the weighted value, is an important variable which directly controls the energy input to a surface. The recorded relations between air temperature and the gradient are probably a function of the correlation between air temperature and net radiation, where a strong insolation creates a high surface-close temperature. The relation between humidity and the gradient could be of an indirect character, too, as high humidity often is linked to cloudy and cool weather. Concerning the relative humidity, this negative relation to temperature is strengthened as the rise in temperature causes a decrease in relative humidity.

According to the table a correlation between wind velocity and the gradient could be noticed only in 1982. This year the wind tended to repress the development of the gradient. However, an indirect effect of the wind was noticed in 1981, where the net radiation during conditions with a wind speed less than 4 m/s, at least numerically, had a greater effect on the vertical temperature gradient, than during windy conditions. This was also seen in 1982.

3.4.1.2 Nighttime

The nighttime gradient between +10 cm and +175 cm was much weaker than the daytime gradient, and many times it was even absent. However, some weaker correlations between this variable and the

Table 3.4. Coefficients of correlation (r) with the 95% confidence limits and regression (k), describing the relation between the air temperature gradient 10 cm-175 cm and some other meteorological variables. Daytime 1981 at 15 h, and 1982 at 16 h.

		k	r
Air Temp.	1981	$1.4 \cdot 10^{-1}$	0.58+/-0.14
	1982	$1.4 \cdot 10^{-1}$	0.57+/-0.18
Net Radiation	1981	$4.6 \cdot 10^{-3}$	0.54+/-0.15
	1982	$6.2 \cdot 10^{-3}$	0.64+/-0.16
Net Rad. weighted	1981	$5.1 \cdot 10^{-3}$	0.62+/-0.13
	1982	$6.9 \cdot 10^{-3}$	0.66+/-0.15
Wind Velocity	1981	$6.6 \cdot 10^{-2}$	0.10+/-0.21
	1982	$-2.5 \cdot 10^{-2}$	-0.37+/-0.23
Vapor pressure	1981	$-9.9 \cdot 10^{-2}$	-0.29+/-0.19
	1982	$-1.8 \cdot 10^{-1}$	-0.78+/-0.08

other climatic variables was noticed. In table 3.5 one can see that a stronger outgoing radiation increased the negative vertical gradient. In 1981 a correlation was also noticed between the absolute temperature and this gradient, but this correlation was not found in 1982. The correlation is probably, as above, caused by the link between the net radiation and absolute temperature. In 1982 the vertical gradient was repressed by an increased wind, this did not occur in 1982.

Mattsson (1966) noticed in a similar study a more striking nighttime gradient, especially at calm conditions. The differences in recorded gradients, as well as the effects of the wind, could be caused by the fact that in the present study a lot of data is analysed simultaneously, thus reducing the possibility to find smaller details.

3.4.2 Soil Temperature Gradient under Fallow Ground

3.4.2.1 Daytime

In daytime the temperature at -5 cm was higher than the temperature at -15 cm. As for the air temperature gradient, analyses have shown that net radiation, air temperature, vapor pressure and relative air humidity were linked to the gradient in the soil (table 3.6). The weighted value of net radiation seems to be of more importance than the contemporary value of the net radiation; the differences are not significant, though. A chi-two analysis has, at a confidence level higher than 99%, verified that an increased moisture content was correlated to a reduction of the gradient.

It is not unrealistic to believe that primarily the net radiation is of importance in the development of soil temperature gradients. The recorded relations to both air temperature and relative humidity, can then be a function of these variables being related to the net radiation.

Table 3.5. Coefficients of correlation (r) with the 95% confidence limits and regression (x), describing the relation between the air temperature gradient 10 cm-175 cm and some other meteorological variables. Nighttime 1981 at 3 h, and 1982 at 4 h.

		k	r
Air Temp.	1981	$4.0 \cdot 10^{-2}$	0.28+/-0.18
	1982	$-3.7 \cdot 10^{-2}$	-0.02+/-0.18
Net Radiation	1981	$7.2 \cdot 10^{-3}$	0.30+/-0.19
	1982	$5.3 \cdot 10^{-3}$	0.32+/-0.24
Net Rad. weighted	1981	$6.2 \cdot 10^{-3}$	0.24+/-0.20
	1982	$6.3 \cdot 10^{-3}$	0.35+/-0.24
Wind Velocity	1981	$1.3 \cdot 10^{-2}$	0.49+/-0.30
	1982	$1.6 \cdot 10^{-2}$	0.02+/-0.21
Vapor pressure	1981	$3.3 \cdot 10^{-2}$	0.10+/-0.21
	1982	$-1.4 \cdot 10^{-2}$	0.00+/-0.27

In 1981, no correlation was found between the wind and the gradient. However, on data from 1982 a relation was seen where a higher wind velocity decreased the gradient. This reduction may be a result of the cooling effect of the wind, by increasing the sensible and latent energy losses. Some secondary effects of the wind were noticed, too. For instance, though not statistically verified, a stronger correlation was indicated between net radiation and the temperature gradient in calm conditions than in windy. See also table 3.7.

Table 3.6. Coefficients of correlation (r) with the 95% confidence limits and regression (k), describing the relation between the soil temperature gradient at 15 cm-5 cm and some meteorological variables. Daytime 1981 at 15 h, and 1982 at 16 h.

		k	r
Air Temp.	1981	$-3.7 \cdot 10^{-1}$	-0.69 ± 0.11
	1982	$-1.0 \cdot 10^{-1}$	-0.72 ± 0.10
Net Radiation	1981	$-7.9 \cdot 10^{-3}$	-0.55 ± 0.14
	1982	$-5.0 \cdot 10^{-3}$	-0.61 ± 0.14
Net Rad. weighted	1981	$-8.4 \cdot 10^{-3}$	-0.61 ± 0.11
	1982	$-5.4 \cdot 10^{-3}$	-0.72 ± 0.11
Wind Velocity	1981	$-1.0 \cdot 10^{-2}$	-0.17 ± 0.20
	1982	$1.8 \cdot 10^{-2}$	0.37 ± 0.19
Vapor pressure	1981	$1.3 \cdot 10^{-1}$	0.24 ± 0.19
	1982	$8.1 \cdot 10^{-2}$	0.52 ± 0.16

Table 3.7. Coefficients of correlation (r) with the 95% confidence limits and regression (k), describing the relation between the soil temperature gradient at 15 cm-5 cm and some meteorological variables in daytime 1981 at 15 h, 1982 at 16 h, during situations with weak wind and windy conditions.

During wind velocity <4.0 m/s			
		k	r
Air Temp.	1981	$-4.3 \cdot 10^{-1}$	-0.87 ± 0.09
	1982	$-1.0 \cdot 10^{-1}$	-0.66 ± 0.19
Net Radiation	1981	$-8.9 \cdot 10^{-3}$	-0.77 ± 0.15
	1982	$-5.6 \cdot 10^{-3}$	-0.68 ± 0.19
Wind Velocity	1981	$-3.8 \cdot 10^{-1}$	-0.14 ± 0.38
	1982	$4.1 \cdot 10^{-2}$	0.00 ± 0.44
During wind velocity >4.0 m/s			
		k	r
Air Temp.	1981	$-2.0 \cdot 10^{-1}$	-0.65 ± 0.14
	1982	$-1.0 \cdot 10^{-1}$	-0.78 ± 0.05
Net Radiation	1981	$-8.3 \cdot 10^{-3}$	-0.54 ± 0.17
	1982	$-4.4 \cdot 10^{-3}$	-0.61 ± 0.17
Wind Velocity	1981	$-2.0 \cdot 10^{-1}$	-0.17 ± 0.23
	1982	$1.0 \cdot 10^{-1}$	0.22 ± 0.27

Table 3.8. The daytime temperature gradient between the levels -5 cm and -15 cm, at moist and dry conditions.

	1981	1982
Moist, tension <0.25 bar	-2.4+/-0.4	-1.9+/-0.2
Dry, tension >0.90 bar	-2.7+/-0.8	-2.3+/-0.2

A chi-two analysis did not verify a relation between soil moisture and the vertical gradient. However, numerically the gradient was stronger in dry soil, see table 3.8. A reason for why the gradient was lower in moist soil can be a greater evaporative cooling effect. The influence of soil water on the gradient could also be explained by the effect of soil water on the thermal properties of the soil. At a higher content of soil moisture, both heat capacity and heat conductivity increases (de Vries 1964, among others). The raised heat conductivity will increase the daytime heat flux to deeper layers, hence decreasing the temperature gradient. A raised heat capacity will increase the thermal inertia of the soil, and thus repress the temperature rise and dampen the vertical gradient.

In 1982, an analysis was also made of the temperature gradient between the depths 5 cm and 50 cm. As the temperature at -50 cm hardly is affected by short term weather fluctuations, this analysis could be of interest because of showing how these fluctuations affect the absolute temperature in the top soil.

Of course the net radiation had a great effect on soil temperature. An increase in net radiation by 100 W/m^2 , resulted on average in a relative temperature rise at -5 cm of 2.2°C . However, the variation was rather great; $\pm 3.8^\circ\text{C}$ at the 95% confidence level. A 4.0°C increase in air temperature was linked to a relative soil temperature rise of 2.4°C (± 3.0).

Concerning the wind, the variation was too great for telling anything of the absolute effect.

The analyses of soil moisture show clearly that this variable did affect the surface-close temperature. At moist conditions (soil tension <0.25 bar) the average temperature difference between -50 cm and -5 cm was 2.7°C (± 1.0). At dry conditions (water tension >0.25 bar) this difference was 6.0°C (± 1.0). These differences caused by the soil moisture, are explained by the above mentioned evaporative cooling processes and the change in the thermal properties of the soil.

3.4.2.2 Nighttime

In nighttime it was coolest in the surface-close layers. The analyses showed that there was a correlation between the net radiation and the temperature gradient, where a stronger outgoing radiation was linked to a raised gradient. The correlation was strongest for the weighted value of the net radiation. A correlation between air temperature and the gradient was also found, which, as mentioned above, primarily could be seen as a result of the effect of net radiation on temperature. See table 3.9.

Table 3.9. Coefficients of correlation (r) with the 95% confidence limits and regression (k), describing the relation between the soil temperature gradient 15 cm-5 cm and some meteorological variables in nighttime 1981 at 3 h, and 1982 at 4 h.

		k	r
Air Temp.	1981	$-7.0 \cdot 10^{-1}$	-0.44 ± 0.17
	1982	$-1.0 \cdot 10^{-1}$	-0.46 ± 0.20
Net Radiation	1981	$-1.0 \cdot 10^{-2}$	-0.39 ± 0.17
	1982	$-2.4 \cdot 10^{-3}$	-0.34 ± 0.23
Net Rad. weighted	1981	$-1.3 \cdot 10^{-2}$	-0.46 ± 0.16
	1982	$-3.6 \cdot 10^{-3}$	-0.47 ± 0.20
Wind Velocity	1981	$-1.3 \cdot 10^{-1}$	-0.43 ± 0.17
	1982	$-1.3 \cdot 10^{-3}$	-0.00 ± 0.27
Vapor Pressure	1981	$-9.4 \cdot 10^{-2}$	-0.35 ± 0.16
	1982	$-2.5 \cdot 10^{-2}$	-0.52 ± 0.19

In 1981 an increased wind velocity was correlated to a less steep gradient, maybe an indirect effect due to the fact that a higher wind velocity could be linked to cloudy weather, giving warmer nighttime temperatures. No relations were found between the nighttime gradient and soil moisture.

The gradient was increased by a reduced vapor pressure because of a greater cooling of the surface-close layer. This, too, can be seen as an indirect cause. On clear nights, with low vapor pressure, the energy losses are increased.

3.4.3 Air Temperature Anomaly of a Beet Stand

The recorded air temperature of a beet stand at a height of 10 cm, was compared with the temperature at the same level above a bare soil surface. The difference is called the "anomaly" of the beet stands. In figure 3.23 is presented an overview of the beet stand development during the year.

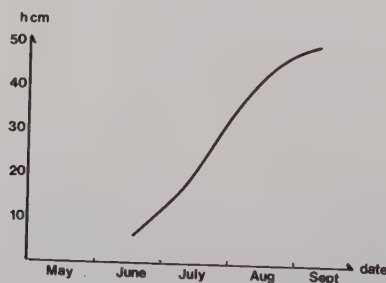


Figure 3.23. Average development of beet stand height in 1981 and 1982.

In the analyses, each month was treated separately. The condition in June 1982 was, because of different technical problems, based only on very few situations. Extra care should therefore be taken in the evaluation of this period.

3.4.3.1 Daytime

During the summer in 1982 in the beet stand, it was in general two degrees warmer at +10 cm than at the same level above the bare ground; this year no change due to the growing stand was noticed. However, the measurements from 1981 show an interesting development of the gradient caused by the growth of the stand. In table 3.10 one can see that the temperature climate this year was hardly affected by the stand in May. In June and July it was warmer in the beet stand, but in August the temperature was lower in the beet stand than over the bare reference surface. This development of the anomaly was probably due to the growth of the beet stand. The following evaluation is illustrated by figure 3.24. In June the beet stand was about 10 cm high, creating an active layer at this level and thus a great positive anomaly. Later, in July, this active layer was moved upwards. Because of this, the positive anomaly at +10 cm decreased. In August the active layer was well above +10 cm. Because of shading effects, a negative anomaly was created at the surface-close layer. A similar development of the microclimate of a crop was noticed by Mattsson (1966) in a growing potato crop.

The reason for why the 1981 temperature development was not repeated in 1982, could be that the stand was more sparse in 1982. The shading effects of the stand in August were therefore reduced.

In the analyses of how other meteorological variables during the summer affect the anomaly of the beet stand, some interesting relations were found (table 3.11). The wind did not have any effect on the anomaly in May, when the stand was still very low. In June the data indicated that a raised wind velocity lowered the positive anomaly of the stand. The stand was now so high, that it created an anomaly, but not high enough for the wind movement to be repressed. Later in the season, in July and August, the wind usually had no effect on the anomaly. The stand was now so closed, that rather strong winds were needed to repress the positive anomaly by ventilation.

Table 3.10. The daytime temperature differences between the air 10 cm above the surface of a beet stand, and the same level above a bare soil surface with the 95% confidence limits.

	1981	1982
May	0.0+/-0.3	-
June	2.2+/-0.7	1.9+/-1.5
July	0.5+/-0.4	2.0+/-0.8
August	-1.4+/-0.4	1.8+/-0.7

Table 3.11. Coefficients of regression (k) and correlation (r) with the 95% confidence limits, recorded from linear regressions between the day-time air temperature anomaly at +10 cm of a beet stand, and contemporary net radiation and wind velocity.

			k	r
Net rad.,	May	1981	$4.1 \cdot 10^{-3}$	0.39 ± 0.39
	June	1981	$3.5 \cdot 10^{-3}$	0.14 ± 0.41
		1982	$6.2 \cdot 10^{-2}$	0.19 ± 0.77
	July	1981	$6.1 \cdot 10^{-4}$	0.09 ± 0.40
		1982	$4.1 \cdot 10^{-3}$	0.19 ± 0.48
	August	1981	$3.3 \cdot 10^{-4}$	0.06 ± 0.63
		1982	$9.2 \cdot 10^{-3}$	0.66 ± 0.26
Wind,	May	1981	$-2.2 \cdot 10^{-2}$	-0.17 ± 0.39
	June	1981	$-3.7 \cdot 10^{-1}$	-0.36 ± 0.27
		1982	$-6.0 \cdot 10^{-1}$	-0.80 ± 0.36
	July	1981	$2.0 \cdot 10^{-1}$	-0.10 ± 0.40
		1982	$-1.2 \cdot 10^{-1}$	-0.14 ± 0.58
	August	1981	$1.0 \cdot 10^{-1}$	0.22 ± 0.60
		1982	$-2.5 \cdot 10^{-1}$	-0.32 ± 0.44

Except for the condition in August 1982, no relation between net radiation and the anomaly was found. However, in August 1982, a raised net radiation was strongly correlated to an increased anomaly. The lack of relations can be explained by the increased transpirative cooling caused by stronger incoming radiation, which represses the temperature rise in the uplifted active layer of the beet stand.

3.4.3.2 Nighttime

Apart from June 1981, the air was in nighttime generally somewhat cooler at the beet stand than above the reference surface (table 3.12). Mattsson (1966) noticed in the contrast to this a generally higher temperature in the air under a potato stand, 10 cm above the ground, than above a bare surface. The fact that it was cooler under the beet stand, could be due to lesser heating of the soil under the beet stand during the days. The nighttime heat compensation of radiative energy losses may therefore be reduced. This is supported by the fact that the nighttime soil temperature, too, was lower under the beet stand than under the bare ground. The differences in structure of a beet stand and a potato stand could explain the different results of this study and of Mattsson's study. The broad basal leaves in a beet stand more efficiently screens off the incoming radiation during the day. This results in a reduced heating of the soil and thus less heat is available for compensation of radiative energy losses.

The analysis of the effects of different climatic variables on the anomaly (table 3.13), showed that an increased wind velocity raises the negative anomaly of the beet stand. The reason for this could be that the compensating effect of the wind on the radiative energy losses is depressed in the sheltered beet stand.

Table 3.12. The nighttime temperature anomaly 10 cm above the surface in a beet stand, in relation to the same level above a bare soil surface with the 95% confidence limits.

	1981	1982
May	-0.6+/-0.1	-
June	1.6+/-0.7	-0.2+/-0.2
July	-0.4+/-0.1	-0.7+/-0.2
August	-0.6+/-0.4	-0.6+/-0.3

Table 3.13. Coefficients of regression (k) and correlation (r) with the 95% confidence limits, recorded from linear regressions between the nighttime air temperature anomaly at +10 cm in a beet stand, and contemporary net radiation and wind velocity, respectively.

		k	r
Net rad., May	1981	$-8.5 \cdot 10^{-3}$	-0.45+/-0.36
Net rad., June	1981	$-3.1 \cdot 10^{-2}$	-0.42+/-0.36
	1982	$-8.8 \cdot 10^{-2}$	-0.88+/-0.34
Net rad., July	1981	$-4.9 \cdot 10^{-3}$	-0.14+/-0.59
	1982	$5.7 \cdot 10^{-2}$	0.23+/-0.39
Net rad., August	1981	$-1.0 \cdot 10^{-2}$	-0.29+/-0.61
	1982	$-1.4 \cdot 10^{-2}$	-0.60+/-0.34
Wind May	1981	$7.5 \cdot 10^{-3}$	0.00+/-0.40
Wind, June	1981	$-1.9 \cdot 10^{-1}$	-0.00+/-0.42
	1982	$-3.0 \cdot 10^{-2}$	-0.00+/-0.95
Wind, July	1981	$-8.3 \cdot 10^{-2}$	-0.37+/-0.52
	1982	$-2.2 \cdot 10^{-1}$	-0.69+/-0.22
Wind, August	1981	$-2.7 \cdot 10^{-1}$	-0.49+/-0.50
	1982	$-1.5 \cdot 10^{-1}$	-0.54+/-0.38

However, the effect of the wind on the temperature anomaly is limited; at a velocity of 5 m/s the anomaly is on average increased only half a degree. This evaluation is supported by the fact that the effect was greater later in the year when the stand was higher. In May the anomaly was not affected by the wind, but in August, an increase of 5 m/s, did raise the anomaly by roughly one degree.

The net radiation seems to be negatively correlated to the anomaly, where a stronger outgoing radiation reduces the temperature above the bare surface more than in the beet stand. In the latter a strong counter-radiation from the leaves compensates the radiative losses and thus reduces the cooling.

3.4.4 Soil Temperature Anomaly at a Beet Stand

3.4.4.1 Daytime

In daytime the soil in general was cooler under the beet stand than under the reference surface. This negative anomaly was stressed by the growing stand and in August it was for the two years 4.3°C (+/-1.0) and 4.5°C (+/-0.9), respectively. The month-

Table 3.14. The daytime temperature anomaly 5 cm below the ground surface in a beet stand, in relation to the same level below a bare soil surface, with the 95% confidence limits.

	1981	1982
May	-0.8+/-0.2	-
June	-1.4+/-0.4	-0.2+/-0.5
July	-3.7+/-0.5	-3.7+/-0.8
August	-4.3+/-1.0	-4.5+/-0.9

Table 3.15. Coefficients of regression (k) and correlation (r) with 95% confidence limits, recorded from linear regressions between the daytime soil temperature anomaly at -5 cm under a beet stand, and contemporary air temperature, net radiation and wind velocity.

		k	r
Air Temp., June	1981	$-1.1 \cdot 10^{-1}$	-0.30+/-0.38
	1982	$1.4 \cdot 10^{-1}$	0.62+/-0.50
Air Temp., July	1981	$-3.0 \cdot 10^{-1}$	-0.68+/-0.22
	1982	$-3.8 \cdot 10^{-1}$	-0.65+/-0.23
Air Temp., August	1981	$-5.2 \cdot 10^{-1}$	-0.89+/-0.13
	1982	$-2.3 \cdot 10^{-1}$	-0.77+/-0.26
Net rad., June	1981	$7.3 \cdot 10^{-4}$	-0.00+/-0.42
	1982	$3.6 \cdot 10^{-3}$	-0.64+/-0.48
Net rad., July	1981	$-2.2 \cdot 10^{-3}$	-0.22+/-0.38
	1982	$-5.5 \cdot 10^{-3}$	-0.00+/-0.41
Net rad., August	1981	$-5.4 \cdot 10^{-3}$	-0.41+/-0.52
	1982	$-5.4 \cdot 10^{-3}$	-0.00+/-0.39
Wind, June	1981	$6.0 \cdot 10^{-3}$	0.00+/-0.42
	1982	$-1.0 \cdot 10^{-1}$	-0.00+/-0.42
Wind, July	1981	$7.0 \cdot 10^{-2}$	0.00+/-0.42
	1982	$3.8 \cdot 10^{-1}$	0.18+/-0.38
Wind, August	1981	$4.1 \cdot 10^{-1}$	0.35+/-0.55
	1982	$2.1 \cdot 10^{-1}$	-0.00+/-0.41

ly differences of this anomaly (presented in table 3.14) are verified by factor analyses.

In June no stronger relations could be found between the anomaly and contemporary climatic variables, but in July and August a statistically significant effect of the general air temperature on the soil temperature anomaly was noticed (table 3.15). The greater heating of the soil at a certain depth under the bare surface in relation to the same depth under the beet stand, was a result of the layer under the beet stand being at a greater thermal depth than the layer under a bare surface. No other stronger relations between the anomaly and contemporary climatic condition were found. Surprisingly the correlation between the anomaly and the net radiation is absent.

3.4.4.2 Nighttime

In nighttime the soil under the beet stand was cooler than the soil under the bare ground. This is surprising as the beet stand represses the nighttime energy losses. The anomaly increased numerically with the growing stand (table 3.16), but a factor analysis could not statistically verify this development. The received result, a lower temperature under the beet stand in nighttime, could be a delayed effect of the daytime reduced energy input to the soil shaded by the stand. This is supported by the fact that a repression of the nighttime energy losses caused by the insulating beet stand still could be noticed as the nighttime negative anomaly was lower than the daytime negative anomaly. The same result was found for the nighttime anomaly of the air temperature.

Of the examined variables no consequent relation was recorded (table 3.17). However, a tendency was found for a raised wind velocity to cause a reduction of the anomaly, probably by a more efficient cooling at the bare surface.

3.4.5 Discussion

Analyses of the impact of weather on the vertical air temperature gradient showed that this gradient was mainly affected by the net radiation, even if a minor impact of the wind also was seen.

The gradient in the soil was also affected by the net radiation. The correlations with the net radiation in general improved by using the weighted value of net radiation (formula 3.5). Numerically the daytime gradient was lower in moist soil. This could be a result of both an increased evaporation and changes in the thermal properties of the soil.

In 1981 the temperature anomaly of a beet stand changed with the growing stand. In June this year the anomaly was the greatest, +2.2°C. The anomaly decreased later in the season, which reflects the development of the vertical gradient as it is presented in figure 3.24. However, such a result was not recorded in 1982. In the nighttime the air temperature was always lower in the beet stand, than in the bare ground. This anomaly was also affected by net radiation and wind velocity.

Table 3.16. The nighttime temperature anomaly 5 cm below the surface in a beet stand, in relation to the same level below a bare soil surface, with the 95% confidence limits.

	1981	1982
May	-0.1+/-0.1	-
June	-0.3+/-0.4	-1.3+/-1.2
July	-2.2+/-0.5	-2.4+/-1.9
August	-2.5+/-0.6	-1.8+/-1.8

Table 3.17. Coefficients of regression (k) and correlation (r) with the 95% confidence limits, recorded from linear regressions between the nighttime soil temperature anomaly at -5 cm under a beet stand, and contemporary air temperature, net radiation and wind velocity, respectively.

		k	r
Air Temp., June	1981	$-3.6 \cdot 10^{-2}$	-0.00 ± 0.42
	1982	$-8.0 \cdot 10^{-3}$	-0.00 ± 0.43
Air Temp., July	1981	$-6.9 \cdot 10^{-2}$	-0.07 ± 0.40
	1982	$-1.1 \cdot 10^{-2}$	-0.20 ± 0.40
Air Temp., August	1981	$-2.9 \cdot 10^{-2}$	-0.00 ± 0.63
	1982	$1.3 \cdot 10^{-2}$	0.00 ± 0.60
Net rad., June	1981	$6.5 \cdot 10^{-3}$	0.08 ± 0.43
	1982	$1.1 \cdot 10^{-2}$	0.84 ± 0.29
Net rad., July	1981	$1.6 \cdot 10^{-2}$	0.21 ± 0.38
	1982	$1.9 \cdot 10^{-2}$	0.31 ± 0.37
Net rad., August	1981	$-2.7 \cdot 10^{-3}$	-0.46 ± 0.47
	1982	$8.6 \cdot 10^{-3}$	0.00 ± 0.10
Wind, June	1981	$6.9 \cdot 10^{-2}$	0.04 ± 0.43
	1982	$-5.2 \cdot 10^{-2}$	-0.37 ± 0.86
Wind, July	1981	$3.1 \cdot 10^{-0}$	0.54 ± 0.26
	1982	$3.7 \cdot 10^{-1}$	0.48 ± 0.35
Wind, August	1981	$1.5 \cdot 10^{-0}$	0.00 ± 0.63
	1982	$2.8 \cdot 10^{-0}$	0.32 ± 0.57

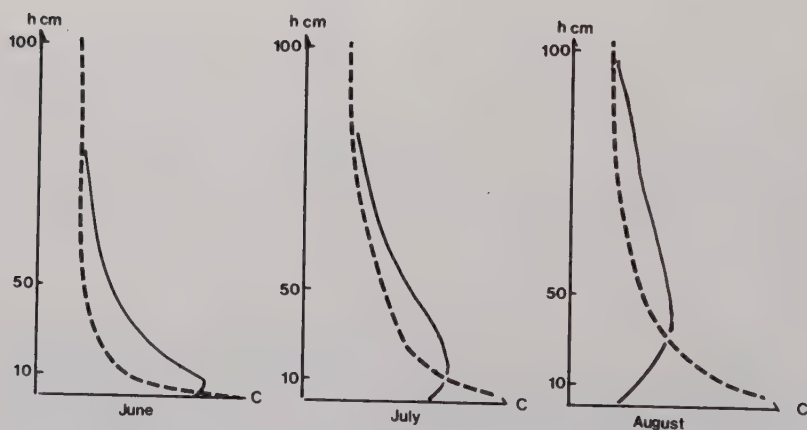


Figure 3.24. Evaluation of the generalized development of the vertical temperature gradient during the summer of 1982 at a beet stand (solid line), and over bare ground (broken line).

The temperature of the surface-close soil layers was always lower under the beet stand, and this difference increased with the growth of the stand. No stronger correlations were found between this anomaly and the contemporary weather conditions.

3.5 SUMMARY

This chapter started with a description of a model for estimating the daily surface-close temperature variation. The model is based on a normalized development of the daily fluctuation of the temperature at the area and the actual extremes of the day. With the model it is possible to make accurate estimations of the daily mean temperature as well as the actual temperature at a certain hour of the day.

The study also showed how the surface-close temperatures are affected by the surface itself and how strong gradients are developed close to the crop.

The impact of the crop on the crop-close environment was analysed, too. Here was seen that the crop moderates the exchange of energy at the soil surface, both by shading effects and because of a reduced wind velocity. Besides lifting up the active layer to the upper parts of the stand, the crop diluted this layer vertically. The exchange of energy does not take part at a single distinct surface (which is the case when vegetation not is present), but within a three-dimensional space, in an active layer consisting of a great number of surfaces. By this, the thermal effects at the boundary layer are reduced.

This study has quantified the importance of other meteorological variables on these surface-close temperature gradients. The net radiation and wind velocity were often found to be of special importance. However, the impact of these variables might easily be disturbed by other meteorological factors; like evaporation, relative humidity (affecting the evaporation), soil moisture (affecting both evaporation and the thermal properties of the soil) and wind direction. Other factors, too, like crop structure and soil characteristics, can affect the relations. As different relations interfere with each other, the impact of the most important meteorological variables shows a great variation.

4 SOIL MOISTURE, AIR HUMIDITY AND EVAPORATION

4.1 WATER SORPTION AND RESORPTION IN SOIL, GENERAL PROCESSES

4.1.1 Introduction

This part of the work will give a brief overview of how the soil moisture in general changed at three levels, 5 cm, 10 cm and 50 cm under bare ground and under a beet stand. The work deals with the vegetation period during the three years 1981, 1982 and 1983. The potential evaporation, too, is discussed. Some experiments that studied in more detail how different factors affect the sorption are presented in part 4.3, dealing with the actual evaporation, and chapter 8 dealing with soil management.

In this experiment the soil water content was measured almost daily with gypsum blocks. The potential evaporation was measured by an Andersson evaporimeter, and the actual evaporation was measured by weighing pans filled with soil. Further information on the technique used and its advantages and disadvantages is presented in chapter 2.

4.1.2 Water Resorption

The changes in soil moisture under bare ground and under the beet stand after precipitation (when the soil initially was thoroughly dried out) were studied. These studies were made at different depths in the soil; various amounts of precipitation were also taken into account. In figures 4.1-4.2 are presented some of the recorded relations.

Chi-two analyses showed a correlation (with 95% significance) between the amount of precipitation and final water tension, both for the bare ground and the soil under the beet stand, at the levels -5 cm and -10 cm. The tests did not show any correlations for the situation 50 cm below the beet stand. At this level under the bare ground the soil almost never dried out. It was therefore not possible on the basis of this material to make any analysis on the changing soil water content. The effect of precipitation on soil moisture is of course obvious and not very surprising. The analyses showed that the soil moisture at deeper levels is hardly affected by a single ordinary rain shower. The figures also indicates a threshold value for how much precipitation was needed for a major effect on the water content at different levels. Usually the soil under the bare ground needed at -5 cm, at least 4 mm of rain to get well saturated with water. At the level -10 cm, the demand was slightly higher. Corresponding values for the more loose soil under the beet stand were for both levels 4 mm. At the soil under the beet stand it was noticed that the onset of water retention was delayed by the intercept and by water caught by the top soil. It should, however, be stressed that these results could only be credited to the analysed soil at the examined conditions, care should be taken before applying these results to other soils.

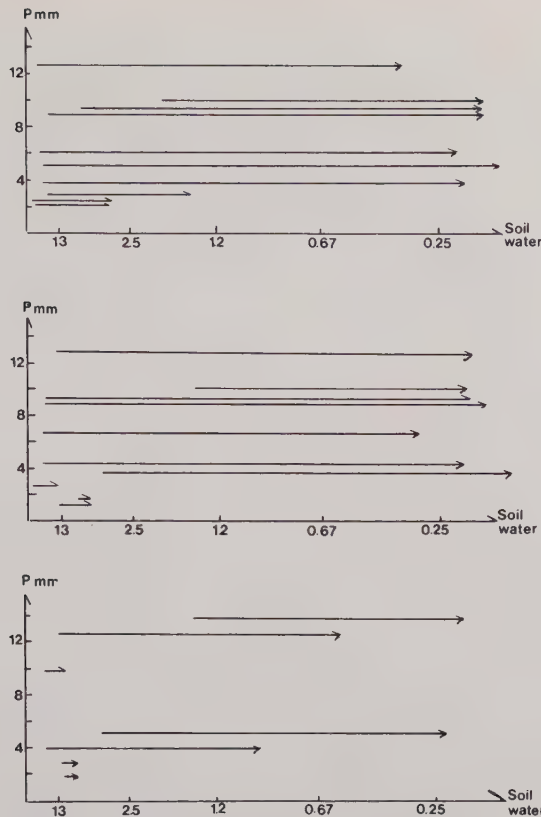


Figure 4.1. Presentation of the received changes in soil moisture content (indicated by arrows) with initial different moisture contents and different amounts of precipitation, under bare ground at the depths 5 cm (top), 10 cm (middle) and 50 cm (bottom). Data from 1981 and 1982. Soil moisture content in bars.

Chi-two analyses showed with 90% significance that the water resorption at -10 cm, in spite of the effects from the intercept, was more efficient under the beet stand than under the bare ground. This is caused by a higher hydraulic conductivity in the looser soil under the beet stand. At some occasions, when measurements of soil moisture were made shortly after the beginning of a light rain spell, a slight delay in the onset of water retention under the beet stand was noticed (figure 4.3). This delay was interpreted as a result of the intercept. As the soil almost never dried out in the deep layer under the bare ground, comparisons between the resorption under the beet stand and under the bare ground could not be done.

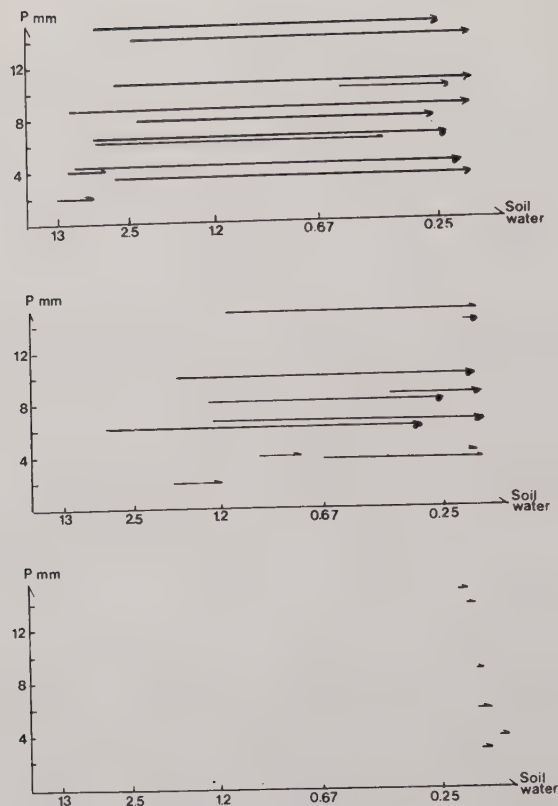


Figure 4.2. Same as figure 4.1, but describing the situation under a beet stand.

4.1.3 Water Sorption

When analysing the drying process, different situations with longer periods of sorption were picked out, and the changes in soil moisture at the three levels -5 cm, -10 cm and -50 cm were examined.

The speed of the drying process was measured in the daily change of pF , the negative logarithm of soil water tension in bars, as this rate throughout the whole period of drying fluctuated around a constant level. In general the rate was found to be faster under the beet stand than under the bare ground, at both levels -5 cm and -10 cm (table 4.1). The received differences were, by pooled t-tests, found significant at the 95% level of confidence. At the deepest level, -50 cm, the soil almost never dried out under the bare surface; but under the sugar beet stand the soil dried out at this level, too. This drying was pronounced in the late season when the stand was well closed and the transpiration was effective, but it was also evident under the young beet stand in the early season. These conditions indicate that the increased

Table 4.1. Recorded rates of drying, measured in average daily change of pF, of the four positions, -5 cm, -10 cm; with and without a beet stand, with the 95% confidence limits. Based on longer periods of desorption, during the field periods in 1981-1983.

	Bare ground	Beet stand
-5 cm	1.55+/-0.13	2.62+/-0.26
-10 cm	1.37+/-0.13	1.87+/-0.13

water resorption is partly caused by the water uptake and transpiration of the stand, but that it is probably also a result of the tilled soil being more sensitive to evaporation, perhaps a result of an increased conductivity for water vapor in the looser soil under the beet stand, or reduced capillary raise.

No significant covariation was found by chi-two tests between the actual rate of drying and the potential evaporative demand, measured with an Andersson evaporimeter. Analyses have shown a positive correlation between the soil moisture content at the upper 5 cm soil layer and the rate of drying. The relation between soil moisture and the rate of drying is further analysed in chapter 4.3. This correlation was not found at the deeper level, -10 cm.

4.1.4 Conclusions

The changes in soil moisture during the period from mid-July to mid-August in 1982 (figure 4.3), give a good overview of water sorption and water resorption at different levels under the bare ground and the beet stand. The rapid drying of the soil under the beet stand is mainly due to transpiration. Under the bare ground, which at this time of the year is quite compact, the process is much slower, and a noticable sorption is only found in the uppermost layers.

On August 9:th, a period of rain began. This recharged the top layer under both surfaces. In figure 4.3 one can see the short delay in the onset of water retention under the beet stand. This delay was due to the intercept. In spite of the delay, the soil under the beet stand was more swiftly filled with water, as a result of the higher conductivity of tension-free water. The lower conductivity of the exposed bare soil resulted from this soil getting more and more compact during the season since it was not covered by a protecting crop. The differences were increased by the loosening effect of root activity. The retention was slower at deeper layers, and the soil at 50 cm below the surface was recharged first after 18 days and 70.0 mm of rain.

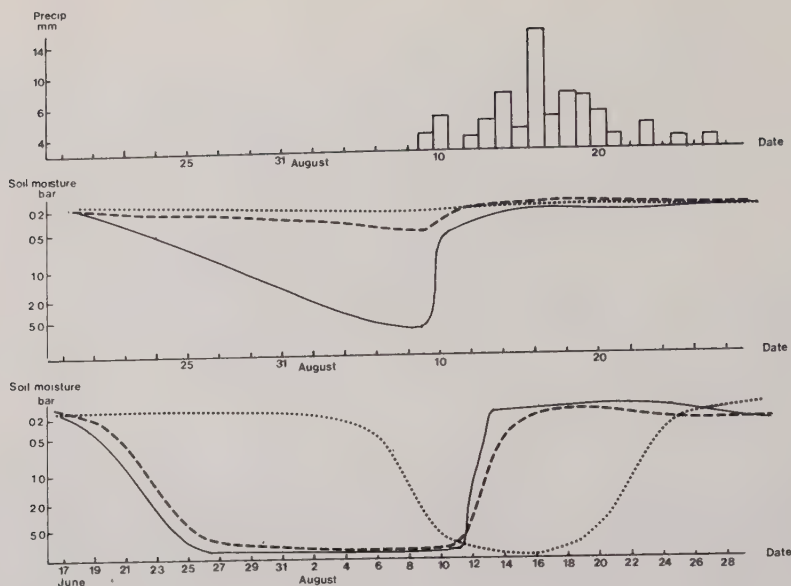


Figure 4.3. Variation in soil moisture at the depths 5 cm (solid line), 10 cm (broken line) and 50 cm (dotted line), under the bare ground (middle) and under the beet stand (bottom). Data from a period in 1982.

4.2 POTENTIAL EVAPORATION

4.2.1 Introduction and Methods

The potential evaporation describes the evaporation when water is not a limiting factor. Even if this variable is more of theoretical character, it is useful when characterizing the evaporative demand. Together with information on the soil water content it can be used when estimating the actual evaporation.

There exist many methods to describe the potential evaporation on the basis of meteorological data. One of the most widespread methods is the equation by Penman (1948), based on energy input, wind velocity and vapor content in the air. The original equation has been improved through the years, both by Penman, and by others, in order to better suit the users' different demands (Fuchs 1973 and Fitzpatrick & Stern 1966).

In Fuchs (op cit), an overview of different formulas for estimating the potential evapotranspiration is presented. These formulas are mainly based either on the solar radiation or on an aerodynamic term, or on both these factors. The aerodynamic formulas use the wind movement and the water deficit in the air. Some formulas are based on the air temperature, as this variable to some extent depends on the net radiation and the available amount of energy. An example of this is Thornthwaite's formula (Thornthwaite 1948). In spite of the lesser accuracy, these temperature-based estimates have the advantage of the temperature being the most intensely measured meteorological variable worldwide.

Another technique for estimating the potential evaporation is the use of evaporation pans. A widely spread reliable evaporimeter is the US Weather Bureau class A pan, but other evaporimeters, as Piches, are also used. In Sweden the Andersson evaporimeter is used quite frequently in agrometeorological studies. This meter is carefully described by Andersson (1969).

In the present study the potential evaporation was measured almost daily during the periods 1981.05.04-07.27, 1982.05.07-08.24 and 1983.05.08-08.07 with an Andersson evaporimeter. On the basis of these measurements the average evaporation in mm/h was calculated. The recorded value of potential evaporation was compared to other meteorological factors and other estimates of the potential evaporation.

4.2.2 Results and Evaluation

The analyses show, at the 95% level of significance, a normal distribution for all the meteorological variables, except the potential evaporation in 1982. In 1982 the potential evaporation was normally distributed only at a significant level just below 90%. If one sample with an extraordinarily high rate of evaporation, 0.65 mm/h, was omitted, this year as well as the other two years, showed a normal distribution at the 99% significant level.

The average rate of potential evaporation for the examined periods in all three years, was 0.21 mm/h. Note that this is an average value, and that there is a great seasonal and daily variation in the evaporation. In a study conducted in the vicinity of Kristianstad, about 50 miles northeast of the investigation site at Ädelholm, Högström (1968) showed an average daily actual evaporation in January of 0.4 mm/day and in July of 2.9 mm/day. In the same study it was shown that the average evaporation in July at noon was 0.24 mm/h and at midnight 0.005 mm/h.

In table 4.2, some of the recorded relations between the potential evaporation and contemporary meteorological variables are presented. A chi-two test showed, at a 99.9% significance, that the potential evaporation was negatively correlated to the relative air humidity (figure 4.4).

In table 4.2 it can be seen that the air temperature and vapor deficit seem to be the most important variables in determining the potential evaporation. Surprisingly, the relation between evaporation and net radiation was absent in the first two years. However, in 1983 a positive relation was found between these variables. For two of the years a negative correlation was found between the vapor pressure and evaporation, but in 1982 no correlation was found at all. No significant effect of the wind velocity is seen; this is surprising. Neither, in general, was the correlation improved by using the sink strength (the product of the wind velocity and the vapor deficit) or the product of temperature and vapor deficit, instead of only the vapor deficit. Some of these relations are also presented in the figures 4.5-4.7.

In table 4.3, the result of some multiple regressions is presented. Here it is seen that the correlation, generally, was not improved by combining an energy variable (temperature or net

Table 4.2. Coefficients of regression (according to the formula $y=kx+l$) and correlation (r), with the 95% confidence limit, at the achieved relations between the potential evaporation in mm/h, according to the Anderssons evaporimeter, and variables describing the contemporary meteorological situation. The independent variables are air temperature ($^{\circ}\text{C}$), net radiation (W/m^2), vapor pressure (bar), vapor deficit (bar), wind velocity (m/s), sink strength, i.e. the product of vapor deficit and wind velocity ($\text{bar}\cdot\text{m}/\text{s}$), and product of temperature and vapor deficit ($^{\circ}\text{C}\cdot\text{bar}$).

Variable	Year	k	l	r
Temp.	1981	$2.8 \cdot 10^{-2}$	$-5.7 \cdot 10^{-2}$	$0.57+/-0.39$
	1982	$1.4 \cdot 10^{-2}$	$-4.0 \cdot 10^{-2}$	$0.65+/-0.19$
	1983	$2.0 \cdot 10^{-2}$	$9.3 \cdot 10^{-2}$	$0.40+/-0.33$
Net rad.	1981	$1.8 \cdot 10^{-4}$	$2.1 \cdot 10^{-1}$	$0.00+/-0.57$
	1982	$3.7 \cdot 10^{-4}$	$1.3 \cdot 10^{-1}$	$0.13+/-0.34$
	1983	$9.4 \cdot 10^{-4}$	$6.9 \cdot 10^{-2}$	$0.76+/-0.16$
Vapor pr	1981	$-5.3 \cdot 10^{-2}$	$7.8 \cdot 10^{-1}$	$-0.41+/-0.48$
	1982	$-6.3 \cdot 10^{-2}$	$2.8 \cdot 10^{-1}$	$-0.00+/-0.48$
	1983	$-3.9 \cdot 10^{-2}$	$6.5 \cdot 10^{-1}$	$-0.59+/-0.25$
Vapor def.	1981	$6.3 \cdot 10^{-2}$	$1.5 \cdot 10^{-1}$	$0.71+/-0.20$
	1982	$2.5 \cdot 10^{-2}$	$1.3 \cdot 10^{-1}$	$0.65+/-0.28$
	1983	$7.1 \cdot 10^{-2}$	$1.5 \cdot 10^{-2}$	$0.81+/-0.12$
Wind	1981	$3.9 \cdot 10^{-2}$	$8.2 \cdot 10^{-2}$	$0.33+/-0.51$
	1982	$-2.6 \cdot 10^{-2}$	$2.5 \cdot 10^{-1}$	$-0.23+/-0.32$
	1983	$-6.6 \cdot 10^{-4}$	$1.9 \cdot 10^{-1}$	$-0.00+/-0.39$
Sink str.	1981	$1.1 \cdot 10^{-4}$	$1.6 \cdot 10^{-1}$	$0.66+/-0.13$
	1982	$8.9 \cdot 10^{-3}$	$1.3 \cdot 10^{-2}$	$0.70+/-0.24$
	1983	$1.7 \cdot 10^{-2}$	$4.4 \cdot 10^{-2}$	$0.47+/-0.30$
Temp*vp.def	1981	$4.7 \cdot 10^{-3}$	$1.4 \cdot 10^{-1}$	$0.71+/-0.23$
	1982	$1.1 \cdot 10^{-5}$	$1.4 \cdot 10^{-1}$	$0.60+/-0.32$
	1983	$2.5 \cdot 10^{-3}$	$3.0 \cdot 10^{-1}$	$0.39+/-0.32$

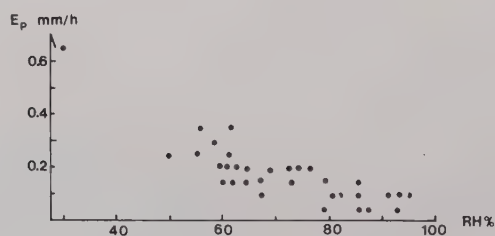


Figure 4.4. Received rate of potential evaporation, in mm/h, as a function of relative air humidity. Data from 1983.

radiation) with an aerodynamic variable, describing the water content in the atmosphere.

Comparisons were also made between the potential evaporation measured by the Andersson evaporimeter and estimates made according the Penman equation:

$$EP = \frac{\frac{\Delta Q}{\gamma L} + 0.5(0.50 + 0.54v)(e_s - e_0)}{\frac{\Delta}{\gamma} + 1}$$

4.1

where Δ is the slope of the saturation pressure curve at mean air temperature, γ the psychrometer constant, Q the daily net radiation, L the latent vaporization heat, v the wind velocity at 1.5 m, e_s the saturation vapor pressure at +1 m and e_0 the daily mean vapor pressure at +0.5 m (1981) or +1 m (1982 and 1983). Actually the vapor pressure should be measured at +1.5 m, but the value at lower levels was used instead, without any corrections. The wind velocity was measured at +5.0 m. The value for that level was then used for a rough estimate of the wind velocity at +1.5 m, by using a formula presented in Liljequist (1962, p 389):

$$u_{1.5} = u_5 \left(\frac{1.5}{5} \right)^{1/7}$$

4.2

where u_5 is the wind velocity at +5 m. The roughness index, $1/7$, is actually somewhat low for the fairly smooth surface at the reference spot. However, this will affect the results of the later evaluations only slightly. The result of the regressions between the different estimates of the potential evaporation shows a good correlation (table 4.4, figure 4.8). The readings of the Anderssons evaporimeter were on average for all three years slightly lower than the Penman estimate (table 4.5).

Table 4.3. Coefficients of regression (according to the formula $y = k_1x + k_2x^2 + 1$) and determination (R^2), received in multiple regressions of the relations between potential evaporation and contemporary meteorological variables.

Variables: x1; x2	Year	k ₁	k ₂	1	R ² %
Temp; vapor pr.	1981	2.8*10 ⁻²	-4.9*10 ⁻²	4.5*10 ⁻¹	48.7
	1982	2.1*10 ⁻²	-8.0*10 ⁻³	-4.1*10 ⁻²	42.5
	1983	3.8*10 ⁻²	-5.5*10 ⁻²	3.1*10 ⁻¹	76.3
Vapor def.; wind	1981	6.8*10 ⁻²	-1.0*10 ⁻²	1.8*10 ⁻¹	49.0
	1982	2.7*10 ⁻²	6.4*10 ⁻³	1.1*10 ⁻¹	39.7
	1983	7.3*10 ⁻²	1.3*10 ⁻²	-3.5*10 ⁻²	66.3
Sink str.; net rad	1981	6.4*10 ⁻²	-2.0*10 ⁻⁵	1.6*10 ⁻¹	48.3
	1982	8.8*10 ⁻³	4.0*10 ⁻⁴	8.5*10 ⁻²	49.9
	1983	1.0*10 ⁻⁴	6.2*10 ⁻⁴	2.3*10 ⁻²	70.7
Vapor def.; net r.	1981	6.4*10 ⁻²	6.4*10 ⁻⁶	1.4*10 ⁻¹	51.4
	1982	2.4*10 ⁻²	3.0*10 ⁻⁴	9.6*10 ⁻²	41.5
	1983	4.7*10 ⁻²	4.5*10 ⁻⁴	1.6*10 ⁻²	71.0
Temp.; vapor def.	1981	-1.3*10 ⁻²	8.4*10 ⁻²	2.5*10 ⁻¹	47.8
	1982	1.0*10 ⁻²	1.3*10 ⁻²	1.9*10 ⁻²	38.5
	1983	3.4*10 ⁻²	8.1*10 ⁻²	3.6*10 ⁻²	70.3

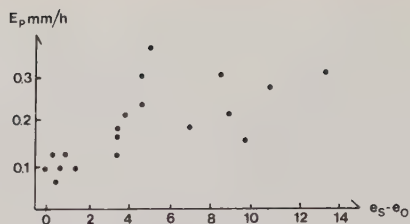


Figure 4.5. Received rate of potential evaporation, in mm/h, as a function of vapor deficit in the air, in bar. Data from 1982.

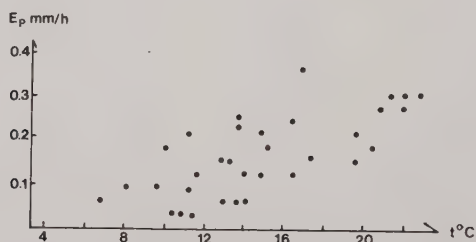


Figure 4.6. Received rate of potential evaporation, in mm/h, as a function of contemporary air temperature. Data from 1982.

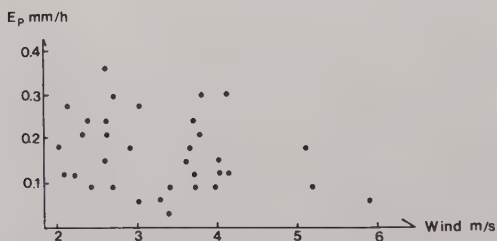


Figure 4.7. Received rate of potential evaporation, in mm/h, as a function of contemporary wind velocity. Data from 1982.

The present correlation between the two methods is not so good as the correlation received in a similar study by Johansson (1969). Johansson also showed the importance of the vertical position of the evaporimeter. The evaporation was greatly increased on clear days by an increased height. However, both in Johansson's study and in the present study, the measurements were made at roughly the same level.

Table 4.4. Coefficients of regression (according to the formula $y=kx+l$) and correlation (r) with the 95 % confidence limits, for the recorded relations between the Penman rate of actual evaporation (EP) and the Andersson estimate of the actual evaporation (EA).

Year	l	k	r
1981 EP = $1.9 \cdot 10^{-1}$	$+ 2.6 \cdot 10^{-1}$	EA	0.50+/-0.30
1982 EP = $8.1 \cdot 10^{-2}$	$+ 3.3 \cdot 10^{-1}$	EA	0.55+/-0.35
1983 EP = $1.3 \cdot 10^{-2}$	$+ 7.3 \cdot 10^{-1}$	EA	0.82+/-0.12

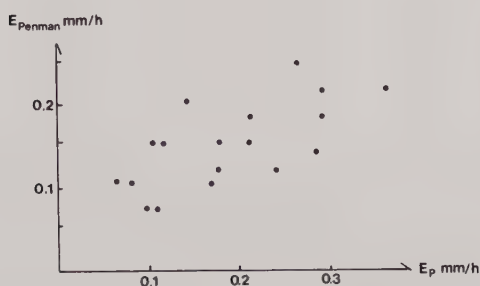


Figure 4.8. Received relations between the potential evaporation by Andersson and the estimate by Penman. Data from 1982.

The average daily evaporation, according to the formulas of Penman and Thornthwaite, for the different months of the field period is presented in table 4.5.

The examined climatic parameters affect the potential evaporation in different ways. The temperature and net radiation determine the energy support to the evaporation process. As the evaporation is measured by a solitary meter, placed in the air, the energy input is also due to the sensible heat in the air, and not only to the radiative heat. Therefore the air temperature and not only the net radiation is of great importance in affecting the evaporation from the meter. The air humidity represses the evaporation. A strong correlation is also achieved between the evaporation and both relative humidity and vapor deficit. In general an increased wind velocity raises the evaporation, by a more effective water withdrawal from the vicinity of the evaporating surface. However, such a result was not received in these analyses. The reason for this could be that even a very low wind movement is sufficient to ventilate the evaporated water from the air surrounding the exposed evaporimeter.

The higher rate of evaporation in relation to the Penman formula, received by the Andersson evaporimeter, can be a consequence of this meter being much more exposed to the wind than the bare ground.

Table 4.5. Received average daily potential evaporation according to the Andersson evaporimeter (A) and the formulas of Penman (P) and Thornthwaite (T) at the investigation site during the measurement periods. Also the average daily potential evaporation according to Penman at Malmö, close to the investigation site, and the daily evapotranspiration according to Thornthwaite, during the period 1931-60 are presented. Here the Penman evaporation is based on data from Wallén (1966) and the evaporation according Thornthwaite is based on the Swedish Meteorological and Hydrological Institute's official temperature data from Lund.

Year	Method	May	June	July
1981	A	6.1	2.4	4.5
	P	6.2	5.1	5.3
	T	6.0	5.5	6.3
1982	A	3.2	3.7	4.1
	P	3.5	2.4	3.5
	T	5.2	7.4	9.0
1983	A	1.8	4.3	5.4
	P	2.4	4.1	-
	T	5.4	7.5	-
1931-60	P	4.3	5.1	4.9
	T	5.8	8.2	9.5

4.2.3 Conclusion

The Andersson evaporimeter is a simple device for determining the potential evaporation. Judging from the present study, the meter seems to be most sensitive to air temperature and vapor deficit, but unaffected by the wind. A good correlation was achieved to the potential evaporation according to Penman, even if the evaporation measured with the Andersson evaporimeter on average was lower, and the received coefficient of regression describing the relation between Andersson and Penman was not 1.00. The differences between Penman and Andersson, can be caused by the meter being more sensitive to the air temperature than to the net radiation, and not being particularly affected by the wind. The last phenomenon may be due to the wind not limiting the evaporation from the exposed meter.

4.3 EVAPORATION FROM SOIL

4.3.1 Introduction

Despite being not so intensely measured, actual evaporation and transpiration are two factors that together with precipitation determine the soil water content. The process of evaporation is due to a complex interaction of atmospheric conditions, soil factors and the crop (Biscoe 1972, Konstantinov 1966 and Penman 1941, among others). The meteorological variables of most interest are the water vapor differences between the evaporative zone and the free turbulent atmosphere, the resistance to water flow

in the intervening layer (Hide 1954, Hanks et al 1967), and the available amount of energy (Benoit & Kirkham 1963, among others). Of importance is also the water flow to the evaporation zone in the soil, or through the crop to the leaves and other evaporative surfaces. Nimah & Hanks (1973) present formulas which on the basis of the atmospheric evaporative demand, soil factors and crop characteristics, estimate the evaporation, evapotranspiration and soil water content as a function of time. The evaporation can also be estimated on the basis of the heat budget, using the Bowen ratio (Webb 1960).

Many studies have shown that the sorption of a soil by evaporation, can be divided into three stages (Bond & Willis 1970, Idso et al 1974, Lemon 1956 and Penman 1941 among others), figure 4.9. The first stage is characterized by a high water loss, mainly depending on the atmospheric evaporative demand. During this stage the capillary water flow towards the surface can support the evaporation. Thus, the soil is wet on the surface. If the evaporative demand is very low, this stage can last for several months: 50 days was shown by Bond & Willis (1970) at the potential evaporation of 1 mm/day. At a higher evaporative demand, this stage will only last a few days.

The second stage begins when the capillary water movement no longer can support the evaporative demand at the surface. The soil surface will therefore dry fast. The evaporation is now limited by the vapor movement from the descending evaporative surface in the soil and the free atmosphere above the soil. The evaporation rate at this stage is characterized by a fast decline. The last stage of evaporation is characterized by a low evaporation at a constant rate, more or less unaffected by the atmospheric conditions. The evaporation is now greatly suppressed by the fact that vapor movement through a soil column thicker than 5-7.5 cm is very slow (Hide 1954).

The fastest rate of water loss appears during evaporation stage one. A very high evaporation rate during this first stage, normally causes this stage to last only a short period. The total water loss during this first stage will therefore be less than at a lower rate of evaporation. This paradox, called the Buckingham effect, was first described by Buckingham in 1907, but is noticed in many studies later (Bond & Willis 1970 and 1971, Benoit & Kirkham 1963 and Penman 1941). The practical importance of the Buckingham effect, whether one can decrease the water loss by raising the the evaporative demand in relation to the water support, has been discussed. Bond & Willis (1970 and 1971) showed

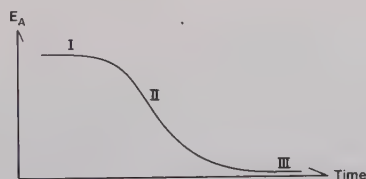


Figure 4.9. Sketch showing the changes in rate of actual evaporation through time. The three stages of evaporation are marked.

that the total water loss during the first 25 days after stage I is accelerated by an increased rate of evaporation at this first stage, but others have shown the opposite effect. This is discussed by Heinonen (1985). The efficiency of the Buckingham effect is also dependant on when the soil will be recharged with water.

The soil water movement in the vapor phase is proportional to the vapor pressure gradient in the soil. This gradient in turn is controlled by temperature and water content. During the night both these factors will normally induce a water flux towards the surface, but in daytime the temperature gradient acts on a downward water movement. Thus, in deeper layers a downward net flux of water vapor could be noticed in daytime (Hide 1954 and Jackson et al 1973). Monteith (1957) showed in a study from England, that the dewfall in nighttime could contribute 0.03 mm of water per hour to the soil.

4.3.2 Methods

The moisture content in aluminium pans filled with soil and placed outdoors at the investigation site, was measured by weighing twice or three times a week during the growing seasons in 1982 and 1983. The pans, 10*14 cm wide and 5 cm deep, were filled to the rim with soil and placed in the ground with the upper edge at the surface level. From these measurements the daily evaporation could be calculated. After rain, the soil samples were changed, and the dry weight of the exchanged soils was determined. It should be noted that the vertical water movement was limited in these shallow pans.

These measurements were repeated in four pans placed in bare ground well exposed to the atmosphere, and the averages were used. On some occasions it was obvious that a bird or rabbit had disturbed the soil in the pans. These measurements were omitted. The actual evaporation was also measured from four pans placed in the beet stand in August 1983, when the crop completely covered the pans.

When examining the evaporation process, correlations were made to contemporary air temperature at +1.75 m, wind velocity at +5 m, air humidity at +1.0 m and soil moisture in the pans. All meteorological variables, except for soil moisture and actual evaporation, were normally distributed at the 95% confidence level. The actual evaporation showed at the 90% confidence level a normal distribution.

4.3.3 Results and Evaluation

In table 4.6, the results of linear regressions between the actual evaporation and some contemporary meteorological conditions are presented. It can be seen that no statistically significant relations between these factors were found. It is even so that the indicated directions of the relations were opposite of what was expected. Neither were any significant relations found after the material was classed into situations with high and low soil moisture content.

Table 4.6. Coefficients of regression (according the formula $y=kx+l$) and correlation (r), with 95% confidence limits, received in linear regressions between the actual evaporation from soil pans and contemporary meteorological variables. Based only on data from 1982.

Variable	k	l	r
Vapor pr.	$6.0 \cdot 10^{-2}$	$-3.0 \cdot 10^{-1}$	$0.18+/-0.53$
Vapor def.	$-9.9 \cdot 10^{-3}$	$5.9 \cdot 10^{-2}$	$-0.45+/-0.45$
Air temp.	$-3.5 \cdot 10^{-2}$	$9.3 \cdot 10^{-1}$	$-0.00+/-0.55$
Net rad.	$-1.0 \cdot 10^{-3}$	$5.7 \cdot 10^{-1}$	$-0.19+/-0.53$
Vapor sink	$-2.4 \cdot 10^{-3}$	$5.3 \cdot 10^{-2}$	$-0.45+/-0.45$

In figure 4.10 one can see that a correlation existed between actual evaporation and soil moisture content. The low actual evaporation from some samples with a high moisture content was caused by a low evaporative demand. Figure 4.11 shows the recorded relation between potential evaporation and actual evaporation. This relation, too, is obviously interfered; this time with some observations of a relatively high actual evaporation, in spite of moderate evaporative demand. This is caused by a high soil moisture content. Figure 4.12 presents an evaluation of how the soil moisture content together with the evaporative demand, affected the actual evaporation. The diagram is based on comparatively few observations in 1982 and 1983, and should only be seen as a rough estimate. In the diagram is seen that both soil moisture content and potential evaporation act as limiting factors on the actual evaporation.

Figure 4.13 shows the rate of evaporative drying during a period of sorption in June 1983. After an initially fast reduction of the evaporation rate, corresponding to the evaporation stage II, there occurred a period of low evaporation at a constant rate of roughly 0.01 mm/h, evaporation stage III. The transition between stage II and stage III is suggested to appear when the clay minerals are covered by film of water, two molecules thick (Idso et al 1974). When comparing the figures 4.10 and 4.13, it could be estimated that the evaporation stage III, began at a soil moisture content in the pans of 4-6%. A similar result was received by Idso et al (op cit).

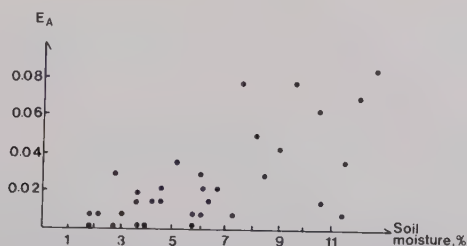


Figure 4.10. The actual evaporation from the pans (in mm/h), as a function of the percental soil moisture content. Based on data from 1982 and 1983.

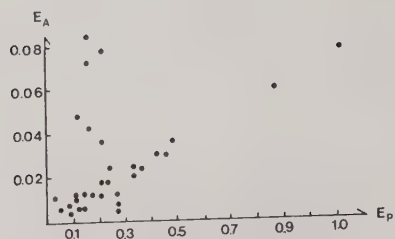


Figure 4.11. Received correlations between the actual evaporation (in mm/h) from the pans, and contemporary evaporation from the Andersson evaporimeter (in mm/h). Based on data from 1982 and 1983.

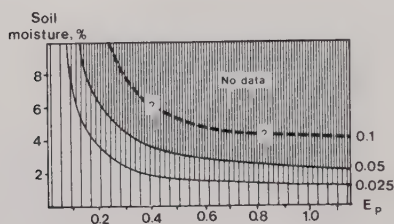


Figure 4.12. A rough estimate of how the potential evaporation (in mm/h) together with the percental soil moisture content have affected the actual evaporation. Based on data from 1982 and 1983. No data describing the situation above the broken line is available.

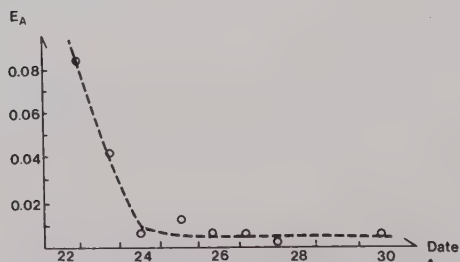


Figure 4.13. Received rate of actual evaporation from the pans during a period of sorption in June 1983 (in mm/h). Based on the average of four pans.

Evaporation stage I is not present in figure 4.13. This is because the length of this stage was too short to be detected by measurements made only daily or every other day. In the above-mentioned study by Idso et al, this period lasted only a day or two. Another reason for why this stage was not represented is that the total water storage is rather limited in a shallow pan. Thus the soil can not support the faster evaporation for any long periods. At an initial soil moisture content of 12%, the pans hold only 6 mm of water, which at an average rate of evaporation of 0.05 mm/h, is exhausted within five days.

The study of the actual evaporation from the pans placed under the beet cover, showed a lower initial rate of evaporation. In figure 4.14, it is seen that the rate of evaporation from the pans under the beet stand, during the first days of exposure, was roughly half of evaporation from the unprotected pans. Consequently, evaporation stage I lasted longer in these pans with a lower evaporative demand. However, the total loss during the first two stages was greater for the exposed pans. From this it

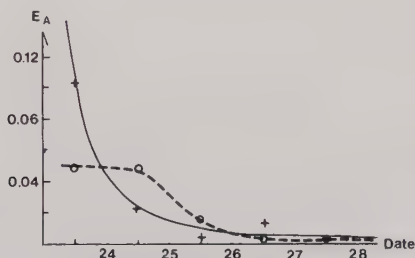


Figure 4.14. Received rate of actual evaporation from pans covered by a closed crop stand (broken line) and without any protection (solid line) during a period of sorption in August 1983, in mm/h. Based on the average of four pans.

can be conducted that the sorption of soil under a closed stand to a great deal is made by transpiration; refer with chapter 4.1. Arkin et al (1974) showed that the daily actual evaporation for a soil decreased from 6.3 mm, when the soil was bare, to 1.9 mm, when the soil was covered by a grain sorghum stand of 50 cm spacing; at 100 cm spacing the recorded daily evaporation was 2.7 mm.

4.3.4 Conclusions

In the exposed pans on the bare ground the evaporation stages II and III could be distinguished. The first stage was not detected here, probably because the stage lasted only less than two days. Another reason for why this stage was not detected, could be that the pans were too shallow to hold sufficient water for longer support of the evaporation processes. Pans twice as deep would probably have improved the result. The transition between the

second and last stages corresponded to a soil moisture content in the pans of 4-6 %. The evaporation from pans covered by a beet stand, was more gentle. Thus, even the first stage of evaporation could be noticed, figure 4.14. The transition between the second and third stages of evaporation under the beet stand corresponded to a soil moisture content of about 8% (as an average of the pan).

It is possible to affect the evaporative losses from the soil of a field with an emerging crop, by modifying the structure of the stand, by trying to establish a closed stand as fast as possible. Of course, the increased transpirative losses by an increased crop density have to be taken into consideration.

A correlation was found between actual evaporation and soil moisture content. However, no correlations were found between the actual evaporation and the contemporary meteorological situation. This is explained by the fact that the evaporation took place at stages II and III, when the atmospheric situation is of less importance. During the second stage, the evaporation is greatly affected by the changing content of soil moisture, thus the correlation between these variables.

4.4 AIR HUMIDITY

4.4.1 Introduction

The air humidity is of importance for the crop since it affects both physiological and meteorological processes. Earlier in this chapter is mentioned the impact of air humidity on evaporation, also condensation is influenced by this factor. In turn these two processes will act on both soil moisture and soil temperature. The amount of dewfall varies greatly with the meteorological situation. The important factors here are dewpoint temperature, air temperature and surface temperature, but also wind, by which moisture can be transported to the surface. The process was carefully analysed by Monteith (1957). In Wallin (1967) several results are presented from studies on dew formation. Here is mentioned that the daily mean dew fall in Europe varies between 0.1 and 0.2 mm, which is about 10% of the precipitation. In northern Europe, the extra input of water due to dew fall is normally of minor importance. In a summer-dry climate, however, the dew fall could be of great importance by increasing the soil moisture (Tuller & Chilton 1973). Of agrometeorological interest is the liberation of latent heat during, dewfall as this process can protect the plants from frost. Furthermore, in the morning when the dew evaporates, the temperature rise will be delayed.

In Wallin (1967) it is also stated that the dewfall can determine whether bacterias and fungis successfully may attack a growing plant.

The transpiration from plants, too, is affected by air humidity, where the external resistance in the transpiration process is reduced by a reduction in relative humidity. In order to prevent water losses the stomatas close during dry periods. This increases the internal resistance when the leaf-to-air water vapor pressure differences are increased. Besides different responses by different species, the closure of stomatas also is affected by growing conditions and plant water status (Jones 1983, p 120).

Two different principles can be used when quantifying humidity content in air. One is based on the absolute amount of water vapor in the air, for instance expressed by the vapor pressure. The other is based on a relative measure of the air humidity amount, expressed by the actual moisture content in relation to the maximal potential water content of the air at the actual temperature. The absolute value is of most interest in studies that deal with the actual mass movement between air and soil or vegetation. In many biological studies which deal with evaporative demand and dehydration, the relative value might be just as interesting.

An aim of this work was to examine variations of air humidity close to the crop and to compare these with the daily humidity development over bare ground. The study also intended to include the effects of other meteorological factors on the air humidity and its development.

4.4.2 Methods

In general, the measurements to support these studies were made with Vaisala's humidity probes. The principle of these sensors is based on humidity-induced changes in electric capacitivity. As liquid water could destroy the calibration, the probes were protected from rainfall by different types of shelters, more carefully described in chapter 2.

In 1980 and 1981, the measurements of air humidity were made at the three levels 5 cm, 10 cm and 50 cm. In 1982 the levels were changed to 10 cm, 50 cm and 100 cm. In all years, the measurements were made both above bare ground and at a growing beet stand. However, in spite of the shelters the probes were frequently disturbed by water as well as by other chemicals. In 1983 and 1984 the air humidity therefore was measured only at a single level. The extra probes then were used for a regular exchange of the recording probes when they lost accuracy.

Some separate measurements of the air humidity at different positions close to the beet stand were made. In these studies small hygrometers by Tradoterm were used. This instrument, too, was based on humidity-induced capacitivity changes.

4.4.3 Results and Evaluation

The problems with the frequently disturbance of the humidity probes' accuracy mentioned in chapter 2, caused the series to be incomplete. A systematic investigation, based on different statistical analyses of the air humidity's daily development at different layers when exposed to various weather situations, was therefore not possible to make. However, different situations when the probes accuracy was satisfying, were picked out and examined separately. Some of these situations are presented in the figures 4.15-4.18. The presented results should be seen as an illustration of the relative humidity's more general daily development. No statistical analyses were made to verify the significance of these relations, neither to quantify the general differences.

In figure 4.15 is shown the development of relative humidity during a calm and cloud-free day when the soil was rather moist. At night the relative humidity was close to 100%, due to this, the actual evaporation now was almost totally reduced. As the temperature rose during the day the relative humidity decreased. The daytime depletion in relative humidity was smallest within the beet stand. Here the moisture content was some 50% greater than the moisture content in the free air above the bare surface. Grace (1983, p 70) and Waggoner & Reifsnnyder (1968) have presented similar results. Besides the lower ventilation within the beet stand, the daytime decrease in relative humidity is restricted by the transpiration, which increases the absolute humidity.

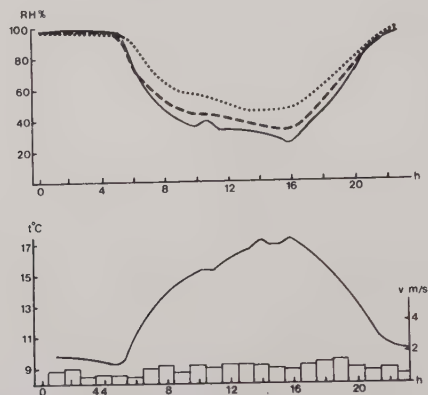


Figure 4.15. The relative humidity at 5 cm (broken line) and 50 cm (solid line) above the bare ground and at 5 cm above the beet stand (dotted line) in June 22, 1980. Below, the hourly wind velocity at 5 m above the ground and screen air temperature are shown.

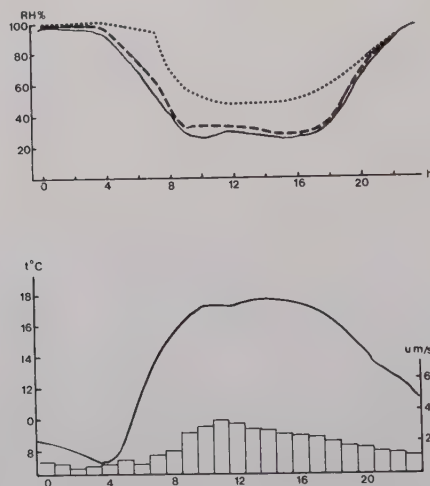


Figure 4.16. As 4.15, but data from June 24, 1980.

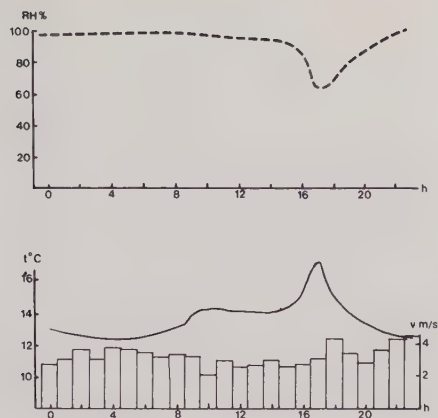


Figure 4.17. As 4.15, but data from June 19, 1980.

Earlier in the year, when the stand was not so developed, the differences in humidity between the air above the bare ground and the air above the beet plants were smaller. Later in the year when the stand was more closed, the differences close to the ground were in general not increased further.

In figure 4.16 is presented the development two days later. Still the sky was more or less cloudless, but the weather was more windy. The soil was somewhat drier in the surface layers. The development of relative humidity was similar as presented in figure 4.15; at noon the lowest values of relative humidity were found at 50 cm above the bare ground and the highest was found within the stand. However, the daytime depletion at 5 cm was now slightly more intense, probably because of the lower moisture content in the soil. Stigter (1977) emphasizes, too, the effect of soil moisture content on the vertical profile of air humidity. Besides this, the stronger and more turbulent windflow also might have reduced the surface-close humidity by increasing vertical losses. In the figures could also be seen that the differences between the two levels above the bare ground were reduced in the more windy situations. This, too, can be seen as a result of the greater turbulence caused by the stronger wind. To some extent the differences of air humidity within the beet stand and above the bare ground were intensified during the windy day. As the rise in wind velocity, increases the ventilation more efficiently in free air than in a sheltered crop.

Figure 4.17 shows the development during a cloudy day. Since the temperature hardly rose in daytime, there was no greater drop in relative humidity. At 17 h an opening in the cloud cover appeared, this raised the temperature and consequently the relative humidity was reduced.

In figure 4.18 the development of relative humidity and vapor pressure during a single day is compared. The nighttime temperature was about 5°C, and at noon the temperature reached 16°C. Here it is seen that in spite of a daytime reduction in relative humidity, the absolute water content in the air was raised during

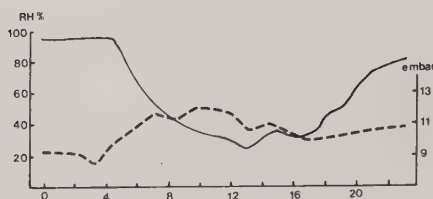


Figure 4.18. Relative humidity (solid line) and vapor pressure in mbar (broken line), data from June 23, 1981.

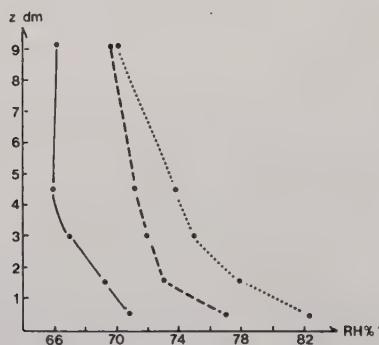


Figure 4.19. Vertical profile of air humidity over bare ground (solid line) and over a beet stand, 25-30 cm in height (broken line) and 35-40 cm in height (dotted line). Based on singular measurements in August 22, 1984.

daytime. This raised vapor pressure was caused by the increased evaporation, which in turn actually was possible by the reduced relative humidity. In the evening the vapor pressure was reduced, by a reduced evaporation. The evaporation was repressed by the increased relative humidity, caused by reduced air temperature and raised dew point temperature. At night, a reduction in vapor pressure was enhanced by condensation of dew.

In figure 4.19 is seen the air humidity gradient over an area of bare ground 10*20 m in size, and at two beet stands of different densities. One stand reached 35-40 cm in height and was completely closed. The other stand reached 25-30 cm and was closed to 70%. The measurements were made at 16-17 h in August 22, 1985, with a general wind of 1.5 m/s, oblique to the rows. The sky had an Altostratus and Altocumulus coverage of 4/8, and the screen air temperature was 17-18°C. Beside the raised relative humidity, is seen in the figure the stronger vertical gradient in the denser stand, due to the reduced ventilation and increased transpiration, in turn caused by the crop.

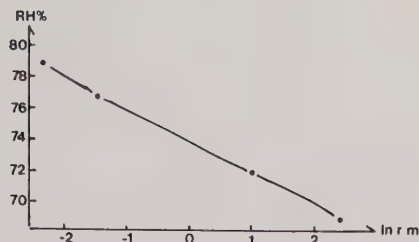


Figure 4.20. The relative humidity at 15 cm above the ground in spacings of different sizes, as a function of the width of the spacing in meters (r). Data from August 22, 1984.

An examination was also made on the spacings effect on air humidity. In this trial, the air humidity was measured at 15 cm above the ground in spacings of different sizes, ranging from 10 cm to roughly 10 m square. In figure 4.20 is shown the logarithmic relation between these variables. Here could also be mentioned that the air humidity at a beet plant, at the same height in a closed stand, was measured to 92.3%.

4.4.4 Conclusions

In summary, the relative humidity on bright days was about 50% higher within the closed beet stand, than over the bare ground. This anomaly is caused by the reduced ventilation within the sheltered crop and the increased input of water to the air volume within the crop through transpiration. The relative humidity is also affected by a change in the absolute air humidity.

During cloudy days, the differences in relative humidity between the beet stand and the free air above bare ground, as well as the daytime depletion, was much reduced and sometimes even absent.

Within spacings of a stand, a logarithmic relation was found between the size of the spacing and the depletion in relative humidity.

4.5 SUMMARY

This chapter has examined the water at the crop site, both soil moisture and air humidity, in comparison to the situation at bare ground.

Under the stand the onset of water resorption during a rainfall was delayed shortly, this, because of the intercept. However, in spite of this delay the resorption generally was faster in the soil under the crop. A cause of this increased rate of water recharge is the more loose soil under the stand.

Measurements of actual evaporation from microlysimeters (small pans filled with soil) were made both at an exposed surface and under a crop cover. These measurements showed that the drying

process was greatly reduced by the vegetation (if one omits the vegetations active uptake of water through their roots). The reduction is caused both by shading effects and reduced wind velocity. The three stages of evaporation could be traced by measurements under crop cover. At the exposed pans (with no crop cover) the first stage was not found, because this stage lasted less than a day, since the rate of drying was more intense.

When comparing soil moisture content at deeper layers under the bare ground and under the crop, it was found that the soil dried at the fastest rate under the crop. The accelerated drying is caused by transpiration.

Measurements showed that the relative humidity on bright days was risen within the beet stand, in relation to the moisture content of the air above the bare ground. This increase was caused both by reduced ventilation and a higher input of water due to transpiration.

An Andersson evaporimeter was used for determining the potential evaporation. The study found that air temperature and vapor deficit affected the device most. A good correlation was achieved between the measurements by the Anderssons evaporimeter and estimations made according the Penman formula. Received differences between these two ways of estimating the evaporation were probably mainly caused by the fact that the evaporimeter was less affected by wind velocity and net radiation.

5.1 INTRODUCTION

5.1.1 Background

The wind is of interest in crop climatological studies as it affects the growth and development of plants, both directly and indirectly through other climatic and physical factors. It is also of interest as the growth and development of the plants affects the wind.

As mentioned earlier in chapter 4, the wind affects the evaporation process which in turn reduces the temperature close to the ground. The wind also modifies the temperature through turbulent and advective transport of sensitive energy.

The wind's role as an agent acting in deflation, transportation and deposition of materials is also well known. These problems are treated by many authors (Morgan 1979, Greeley & Iversen 1985 among others). More directly, the wind acts on plant development by causing different types of physical damage like mechanical injuries through abrasion, breaking and lodging (Jones 1983, p 241-245 and Skidmore 1966). Here can also be mentioned the difficulties caused by the wind when spraying with different herbicides. This increases both the costs and the risks of these treatments.

In general, the yields are improved when crops are grown under more sheltered conditions (Brown & Rosenberg 1971/72 Frank et al 1977 a and Rosenberg 1966). The increased yields can be caused by improved soil moisture conditions and internal soil water status (Rosenberg 1983, p 360) as well as reduced damage by erosion. Brown & Rosenberg (1971/72) showed in a study on sugar beet, how the stomatal diffusion resistance to water vapor and CO_2 was reduced at a lower wind velocity and increased at stronger winds, even if the soil moisture content was constant. However, the effects were greatest under dry conditions. This reduced resistance during calm occasions can increase the photosynthetic rate as the gas exchange is improved, which in turn might increase the yield. Frank et al (1977 b) presented in a study on an irrigated crop that the water use efficiency was greater under sheltered than under wind exposed conditions. These effects of the wind on plant development are thoroughly treated by Grace (1977).

5.1.2 Methods

In all years the general wind was measured at three levels, +10.0 m, +5.0 m and +1.75 m. The instruments used were totalizing over 60 minutes. These measurements were primarily used as reference data for the other studies, however, they were also made in order to describe the general wind flow.

In this chapter wind movements in and close to the beet stand are analyzed. The wind very close to the surface was generally measured by small totalizing cup anemometers mounted on a frame. In some studies the measurements were made with a hot wire anemometer, showing the instant velocity. At these studies the average of some ten readings were used. In chapter 2, the anemometers used are described more carefully.

In 1983 totalizing cup anemometers were placed at the levels +12 cm and +40 cm over the bare surface and at the beet stand. These meters were usually read only once every day or every other day. By this arrangement, the current development of the crops impact on the daily mean wind velocity could be seen.

Periodically, more dense measurements of wind velocities near the the surface were made at several levels over the bare ground and at the same levels at a beet stand. These measurements were made in a stand with normal spacings, as well as in a more sparse stand.

These investigations were also done to show the impact of the row orientation (in relation to the current wind direction) on wind movement close to the surface.

5.2 RESULTS AND EVALUATION

5.2.1 The Wind in General

The wind velocity usually vary sinously during the day, with the strongest winds in daytime and reduced velocities at night. Disturbances from this cycle are generally caused by changes in the general weather situation.

Vertical wind velocity profiles close to the open ground surface have normally a logarithmic shape when the thermal stratification is neutral (figure 5.1). The strong velocity gradients close to the surface are caused by friction. How strong they are depends on the rounghness factor of the surface.

The final shape of the wind profile is modified by the surface and by obstacles in the immediate area. When placing anemometers it is therefore of great importance to choose the site with care. The shape of the vertical profile is affected by the thermal gradient in the atmosphere, too, being more steep under unstable conditions. Fluctuations from this smooth logarithmic profile are generally due to mechanical and thermal turbulence.

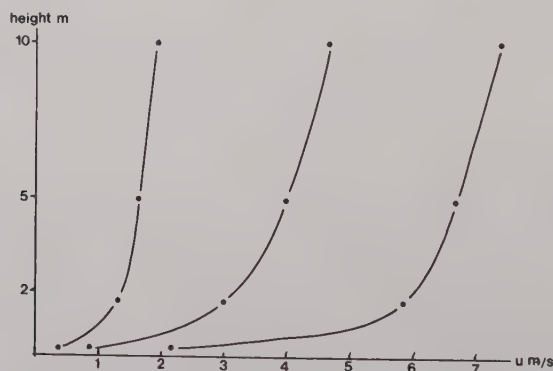


Figure 5.1. Wind velocity at different levels above a bare surface. Data from three situations, describing the relation at strong, moderate and weak winds, respectively. The values refer to averages, totalized over a whole day.

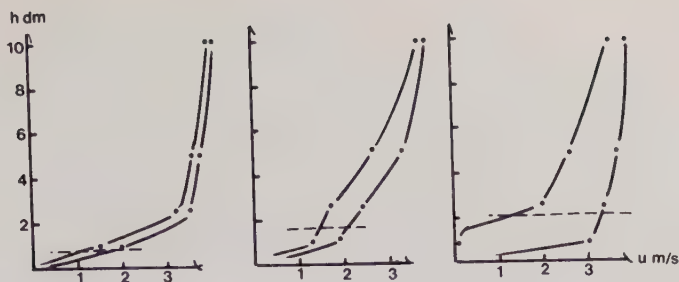


Figure 5.2. Wind velocities at different levels in and above a growing beet stand and above a bare surface (right line). The broken horizontal line shows the height of the stand. The measurements were made by small cup anemometers, and the values are averages of about 10 readings, each lasting some 10 seconds. Data from June 13, June 27 and July 20, 1984

By the growth of the crop, the curve describing the vertical wind profile is successively moved upwards and a level within the stand is acting as a new base level. This fictive surface is called the zero plane displacement (d). In figure 5.2 are presented some profiles at the growing stand, here is clearly seen this zero plane displacement and its rise by the growing stand. This emphasizes the problem of placing a meter that records the general wind above a growing crop.

In Rosenberg et al (1983, p 137) is presented an empirical way to determine this zero plane displacement on the basis of a plot describing the actual relation between the logarithm of the height and the wind velocity. In this method (illustrated in figure 5.3), the height of each reading is subtracted by a constant (an estimated value of the displacement) in order to receive a linear relationship between the velocity and the logarithm of the difference between the actual measured level (z) and the subtracted constant. The value of the constant which makes this relation linear is the sought value of the zero plane displacement (d).

Determinations of the displacement were made in this study, as well, and a very good agreement with the height of the stand (h) was received (figure 5.4). The displacement height was found to be a little bit more than half the stand height. According to the literature the rate d/h varies between 0.5 and 0.8 (Rosenberg et al 1983, p 137 and Oke 1978, p 98). Stanhill (1969) found the following relationship between d and h :

$$\log d = 0.9793 \log h - 0.1536 \quad (r=0.97) \quad 5.1$$

where d is about $2/3$ of h .

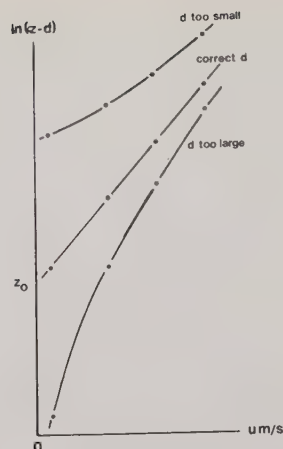


Figure 5.3. Illustration of the empiric way to determine the zero plane displacement, described by Rosenberg (1983, p 137). Consult also the text.

The rate d/h , received in the present study is somewhat low in relation to other experiments. The reason for this can be that the stand in most of the cases, was not completely closed. From the figure could be traced a slight increase in the rate d/h , when the stand was getting higher and more closed.

The roughness length (z_0), was also determined from plots of wind velocity and difference $(z-d)$, by extrapolating the wind velocity to 0. The method used is also described by Rosenberg et al (1983, p 137) This factor was about a tenth of the crop height (figure 5.4). As seen in Szeicz (1969), where the roughness length for several crops is presented, this result corresponds well with other studies.

Thom (1971) suggested that the roughness length is propotional to the difference $h-d$, rather than to the stand height, which makes the length less dependent on the vegetation type. In figure 5.4 b this relation is shown. It is seen that the relationship was not improved. The determined relation differs also from the results by Thom, who found:

$$z_0 = 0.36(h-d) \quad 5.2$$

The analyses presented in figure 5.4 are, however, based on very few observations, and can therefore only serve as an indication of the relations.

In figure 5.5 is presented the rate between wind velocity at 12 cm above the bare ground and the wind velocity at the same height within the beet stand. These measurements were made in 1983, with cup anemometers totalizing over a few days. The successive rise in this rate caused by the growing stand is obvious. The scattering of the rate from a linear development is caused by the general wind velocity, where a wind gust has a stronger influence on the surface close wind velocity over bare ground, than at the same level within the beet stand.

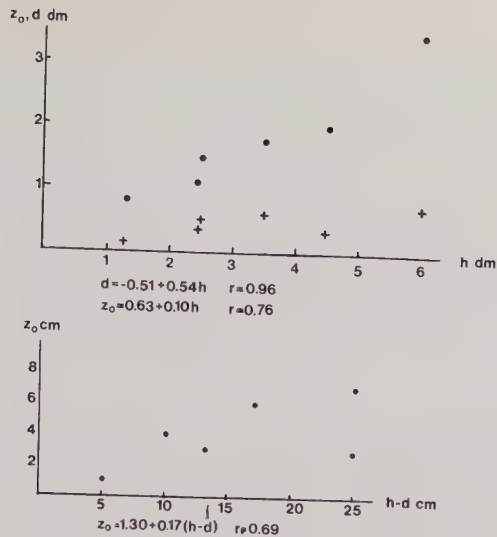


Figure 5.4. Relations between the zero displacement (●) and roughness length (+), respectively, and stand height (top). See also the text. Relation between roughness length and the difference between stand height and zero displacement height (bottom).

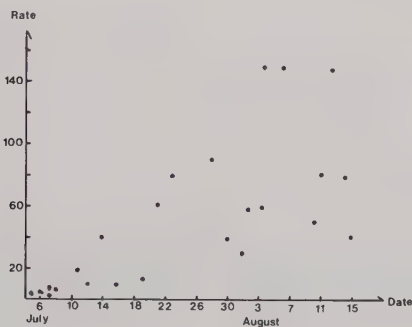


Figure 5.5. Received rate between wind velocity at 12 cm above the bare ground and in the beet stand. Based on readings in which each were totalized over a day.

5.2.2 Effects of Row Spacing

Separate measurements of the wind velocity at stands with rows of different spacings have shown that the spacings effect on the wind were of most importance before the stand became closed within the rows. The effect is also most pronounced in the middle between two rows. Close to the plants as well as at higher levels (above the plant height) the wind velocity was less affected by the different spacings (table 5.1).

The effect of spacing was reduced when the stand became more closed (figure 5.6). However, the wind velocity nearest the

Table 5.1. Wind velocities (in m/s) close to the surface at different row spacings (40 and 120 cm, respectively) and row orientation (at 50 cm spacing). The velocities were measured in the middle between two rows. At the study dealing with spacings, the wind was measured 10 cm leeward of the stand. In the study dealing with orientation, the wind was measured 10 cm leeward of the plants with a wind perpendicular to the rows, and 10 cm to the side of the plants, with a wind parallel to the rows. Based on 10 readings in each position

Experiment	Option	Level	Lee/Side	Middle
Spacing	Narrow	2 cm	0.6	1.1
		10 cm	2.4	2.7
	Wide	2 cm	0.8	1.6
		10 cm	2.3	2.9
Orientation	Parallel	2 cm	1.7	1.9
		10 cm	2.8	3.0
	Perpend.	2 cm	0.6	1.1
		10 cm	2.4	2.7

surface was somewhat stronger at the sparse stand. From the figure is also seen that the zero plane displacement of the two stands was of the same height.

5.2.3 Effects of Row Orientation

In table 5.1 and figure 5.6 the results of some measurements describing the effects of row orientation are presented. It is seen that this orientation affected the wind velocity nearest the surface, both when the stand was newly emerged, and when it had increased its closeness. The effect was higher wind velocities when the wind was parallel to the rows. Furthermore, it is seen that the zero plane displacement level was somewhat lower with wind parallel to the rows. Interesting to note in this figure is the raised velocity very close to the ground under the leaves when the wind is parallel to the rows, compared to the velocity somewhat higher up where the canopy is more dense. Finally, when the stand was well closed, the role of row orientation diminished.

5.3 SUMMARY

The results have shown the successive decrease of wind velocity close to the ground and the raised zero displacement level caused by the growing stand. Also shown was the impact of row spacing and row orientation on the wind velocity within the stand.

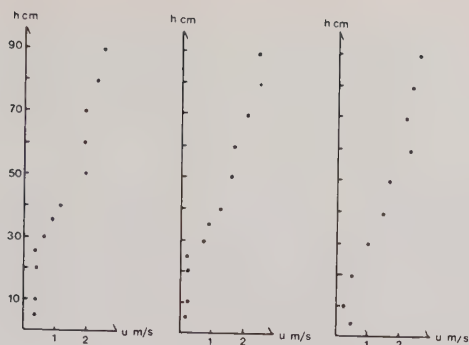


Figure 5.6. Wind profiles with wind perpendicular to rows of 120 and 40 cm spacings (left and middle, respectively), and at a wind parallel to a stand of 50 cm spacings (right). The measurements were made on July 6, 1981 with a hot wire anemometer. Each measurement is based on ten readings.

The results suggest that it is possible to reduce the wind velocity by modifying the stand structure. Interesting to notice is that the row orientation seems to have a greater influence on the wind velocity than the row spacing. This is of special importance in areas where soil erosion is a great problem. If there is a dominant erosive wind direction and if it is possible to place the rows perpendicular to this direction, the orientation is a more efficient way to reduce the wind velocity than row spacing. If the former measure is not possible, an alteration of the row spacing might be a convenient way to reduce the damage induced by strong winds.

The zero plane displacement level of the beet stand was found to be roughly half of the stand height. The somewhat low value of this relation can be caused by the fact that the stand was not closed. The roughness length was found to be a tenth of the stand height.

6 TEMPERATURE AND WIND CLOSE TO A SINGLE PLANT

6.1 INTRODUCTION

Previous chapters have dealt more in general with the climate close to a beet stand and bare ground. In this part of the work, the climate in the absolute vicinity of single plants is presented. This climate exists only a very short distance from the crop, nevertheless it is of interest in crop climatic studies. It is strongly modified by the crop, and can differ greatly from the more general "screen" climate of the field. It represents, as a matter of fact, the real climatic environment of the plants. Finally it should be known that changes in this very crop-close climate, affect the more general microclimate

Not only temperature and wind velocity, but also air humidity is modified close to the plant. In spite of this, no measurements of the humidity, including its very surface-close variation, were made at this scale. However, chapter 4.4 presents some results showing the more general variation of the humidity within the crop.

6.2 TEMPERATURE

6.2.1 Methods

The study on the plant-close temperature climate was mainly done in 1983, but some of the measurements were made earlier.

During the period 1983.07.04-08.31, the crop-close soil temperatures were measured at 3 cm and 10 cm depth. At the deepest layer, these measurements were made both directly under the row, and at the space between two rows. At the shallow layer, the temperature was measured 10 cm to the east and 10 cm to the west of a row (figure 6.1). All the rows had a north-to-south orientation and the distance between two rows was 48 cm. The measurements were made with thermocouples, each thermocouple channel having five sensors in parallel.

In order to see the effect at shaded soil, temperatures were recorded 0.5 cm, 3 cm and 6 cm below a surface covered by a piece of plywood, 40*40 cm in size and placed 10 cm above the surface. Measurements were also made at the same levels under exposed ground. As above, these measurements were made with five sensors in parallel. This experiment was done in July 1982.

In 1982 the air temperature 1 cm above the ground was measured both within a row and in the middle of the space between two rows. The air temperature was measured in 1983 at the meristem of a plant, as well as 5 and 10 cm above the meristem. These measurements were made with only single thermocouples, made of 0.25 mm thick wires. The sensors used were not sheltered as the shield would have disturbed the heat exchange at the bud too much. According to a formula presented in Mattsson (1965), the radiation error of these sensors in a bright day, with a high insolation and a low wind velocity (0.1 m/s) will be only 0.5°C. At a higher wind velocity this error declines rapidly. See also the discussion in chapter 2, dealing with the instruments. By

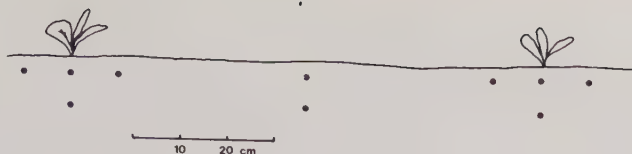


Figure 6.1. The positions of the sensors measuring soil temperatures. The plant rows are marked by beet plants.

using a smaller sensor, the radiation error could be reduced, but these smaller sensors were very easily broken by the plant. When analysing the temperature differences between two positions, the uncertainty caused by radiation error was further reduced.

In 1980 some studies on leaf temperatures were done. The readings were made by contact measurements, using unsheltered thermocouples made of only 0.03 mm thick wires. Measurements made on net radiation are presented in this part of the work, too. These readings were made with a sensor constructed by Siemen Ersking (Denmark).

Because of problems with the paper tape writer in 1983, data from three shorter periods with similar weather situations, were selected manually this year for the analyses. The periods were 83.07.11-07.15, 83.07.25-07.31 and 83.08.09-08.18. The stand was quite open, having a coverage of less than 50% during the first period; in the middle period, the stand was almost closed; and in the last period the stand was dense and well closed, reaching a height of some 40 cm. The weather at the beginning of the first period was sunny, but later in this period it became more cloudy and windy. Both in the second and in the last period, there was a variable cloud cover, with both completely overcast and quite bright days.

6.2.2 Air Temperature

Figure 6.2 presents the daily development of the temperature differences between the meristem and the layers above. One can see that the air in the early period during the day, in general was cooler at the bud than at higher layers. The same daily development, but reduced in amplitude, occurred in mid-July, too. In August the temperature at the bud and at the layer 5 cm above the bud were equal. However, although not significant, it was still somewhat cooler in the lower layers in relation to the layer 10 cm above the bud. Comparisons with the temperature at 10 cm above the bare ground showed that the daytime temperature always was lower in the bud. The cooler daytime temperature at the bud, in relation to both the temperature above the bud and the air at similar level above the bare ground, can be seen as a result of this point being shaded by the leaves, and by the evaporative cooling. The uplifted active layer, described in chapter 3, had probably its essential part a bit above the meristem where the leaves were more horizontally oriented, (figure 6.3). This will increase the temperature above the bud and the negative anomaly of the bud.

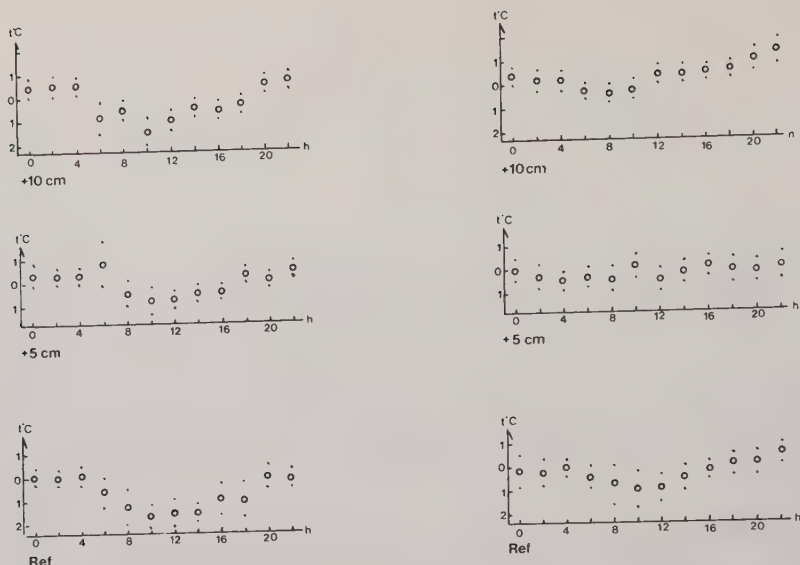


Figure 6.2 Received anomaly in temperatures at the meristem of a beet plant in relation to the temperature 5 and 10 cm above the meristem, and at the same level as the meristem but above bare ground (Ref). A negative value indicates that the temperature was lower at the bud. The left figures describe the situations from 1983.07.11-07.15 and on the right, 1983.08.09-08.18. The 95%-confidence limits are marked, too.



Figure 6.3. The estimated position of the active layer's positive temperature anomaly at a beet plant within a stand.

One reason for the decrease in the vertical temperature gradient right above the meristem later in the season, was that the stand was getting higher. By this the distance between the meristem and the top surface of the stand was increased, and thus the active layer was moved upward. Another reason, discussed in chapter 3, was that the active layer was getting thicker by the more rough top surface of the stand. By this the positive anomaly of the active layer was diluted.

6.2.3 Leaf Temperature

On July 23, 1980, a single examination of leaf surface temperatures was made. A leaf, 2*7 cm in size, was placed horizontally 12 cm above the ground and temperature measurements were made on both sides of the leaf and at the same level in the air above bare ground. At these measurements the plant used was complete with a root, but withdrawn from the soil. These measurements were made with thermocouples made of 0.03 mm thick wires. The thermocouples were placed on the surface of the leaf, and every fifth minute between 11.45 h and 13.55 h a scanning was made. In fact, an integration of the leaf temperature and the leaf-close temperature was recorded instead of the actual leaf temperature. During the experiment the sky was cloudless with only a weak haze and the average hourly net radiation at 12 h, 13 h and 14 h was 455, 445 and 408 W/m², respectively. Contemporary wind velocities at the height of 10 m, were for all three hours 2.7 m/s.

The average air temperature at the reference spot was 21.8+/-0.4° C (at the 95% confidence limit). At the upper surface of the leaf the temperature was 7.3°C (+/-0.7) higher and at the lower surface the temperature was 5.6°C (+/-0.7) higher than the air temperature. These results correspond to similar results by others, which is seen in the following discussion.

The leaf temperature and heat budget of a leaf is a function of the leaf's energy exchange due to radiation, free and forced convection, evapotranspiration and condensation. Factors which in turn are determined by the net radiation, air temperature, air humidity, amount of available water, wind velocity, etc. These relations are thoroughly discussed by Gates (1968). The size of the leaf, too, is of importance; on a smaller leaf (1 cm in size), the leaf temperature is close to the ambient air temperature (Gates & Papian 1971, p 161). Gates (1968) shows that the leaf temperature at lower air temperatures is higher than the surrounding air temperature, but in a warmer situation is instead lower than the temperature of the surrounding air. According to Linacre (1964) the temperature of equilibrium is 33°C. It is thus only at very high temperatures that the leaf temperature is higher than the air temperature. This temperature of equilibrium is however affected by both radiation and other climatic variables (Gates 1968).

The effect of transpirative cooling is shown by Singh & Kanemasu (1983), where the leaf temperature was lower at irrigated plants than at plants suffering from water deficit. This effect is also shown in a study by Monteith (1981); here is seen that the positive temperature anomaly of a leaf was reduced from 5.8°C to 2.7°C, when the stomatas were wide open at a high net radiation (600 W/m²), in relation to completely closed stomatas. The effect of stomatal resistance on transpirative cooling is presented by Waggoner & Reifsnnyder (1968). In their study it is also seen that the positive temperature anomaly is reduced at a lower net radiation, and on overcast days the leaf temperature was, in spite of what is stated above, even lower than the air temperature.

6.2.4 Leaf Temperature under Droplets

6.4.2.1 Introduction

On sunny days when the beet stand was treated with different herbicides, damage was noticed on the beet leaves under the droplets. An early theory for this was that this damage was brought about by high temperatures caused by the concentration of radiation due to refraction in the droplets. In the present study the leaf temperature was measured with 0.5 mm long thermocouples made of 0.03 mm thick wires, placed at the leaf surfaces both under water droplets and under droplets of Betanal, a common herbicide, and on leaves without any droplets.

6.2.4.2 Theory

A light ray striking a water surface (I), will be divided into two rays, one reflected (R) and one refracted (T) the latter transmitting into the water (figure 6.4), according to the formulas:

$$I = R + T \quad 6.1$$

and

$$n_1 \sin \alpha = n_2 \sin \beta \quad 6.2$$

where n_1 and n_2 are the refraction indexes for the two medias (1.00 and 1.33 for air and water, respectively), and α and β , are the angels of incidence and refraction. The rate between R and T is described by the formula:

$$\frac{R}{T} = 0.5 \left[\frac{\sin^2(\alpha - \beta)}{\sin^2(\alpha + \beta)} + \frac{\tan^2(\alpha - \beta)}{\tan^2(\alpha + \beta)} \right] \quad 6.3$$

When light rays perpendicularly strike a semispherical water droplet, the refraction will concentrate the rays at the base of the droplet. In addition the reflection will increase the radiation in a narrow circular zone closely surrounding the droplet (figure 6.5). The reflection losses reduce the effect of the concentration of the rays by refraction. In figure 6.6 is presen-

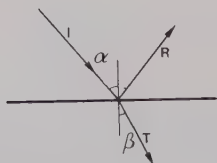


Figure 6.4 The light separation in a reflected (R) and a refracted (T) ray, when a light ray strikes a water surface.

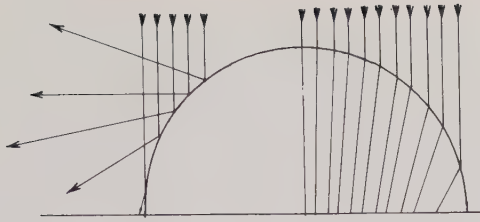


Figure 6.5. The light paths when a light beam strikes a semispherical droplet. The left part of the figure shows the reflection and the right part the refraction.

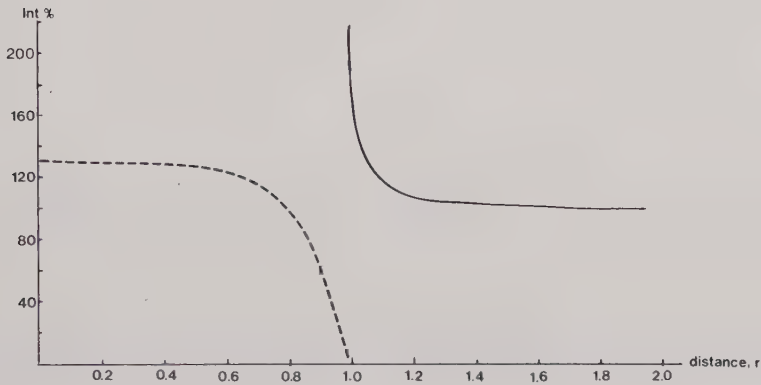


Figure 6.6. The variation of light intensity at the droplet's base level as a function of the distance from the center. The variation is due to reflection and refraction of the incident light striking the droplet perpendicularly. 100% corresponds to a light intensity unaffected by drops.

ted the result of these optical phenomena at the droplet. It is seen here that if one disregards the absorption of the light in the water, the light that reaches the central base area out to 40% of the radius of a semispherical droplet is increased by 30%. At the distance $0.8 r$ the light intensity is greatly reduced. Outside the droplet the light intensity is increased in a narrow zone.

The relations presented in figure 6.6 are only valid for spherical droplets; in bigger droplets the top surface becomes more flat and the concentration of the rays to the center of the base is reduced. Of interest therefore is to know the shape of the droplets on a beet leaf. For this matter droplets of different sizes, placed on leaves were photographed and enlarged 175 times. From these photographs the vertical and horizontal diameters were estimated (figure 6.7), and the rate between the horizontal

radius and the difference between the two radii was determined. The result is presented in figure 6.8. It is seen here that droplets with a horizontal radius lower than 0.4 mm were more or less spherical, and that bigger droplets were also rather spherical. It should, however, be stressed that the diagram is based on very few observations. Similar studies on Betanal droplets showed that the surface tension was much lower for this media and the droplets were much more flat. By this the concentration effect was greatly reduced, and the focus of a Betanal droplet was several cm below the base of the droplet. Furthermore, as the Betanal droplet was more or less opaque, no concentration of the rays due to refraction could occur. Water droplets were also placed on photosensitive paper and exposed to vertical light. From these images it could be seen that the light was concentrated by small semispherical water droplets at the base of the droplets. At droplets greater than some 0.5 cm in diameter, there was seen a slight reduction of the light intensity at the center of the droplet base. This reduction was caused by these bigger droplets' more flat top surface, which does not concentrate any rays.

6.2.4.3 Temperature Measurements

The in situ measurements of temperature at the leaf surface under droplets were made in July 23, 1980 at 13.05-13.55 h and the following day at 11.05-13.15 h. For both days the sky was clear with an average net radiation of 430 W/m^2 and 375 W/m^2 , respectively. The wind velocity 10 m above the ground, was at the two occasions 2.7 m/s and 2.0 m/s, respectively. It was difficult to place the droplets on the sensors after the sensor first had been attached to the leaf. An estimation was made whether the sensor had a central position under the droplet or not.

The leaf temperature in the center of the base of the illuminated droplets was on average 2.6°C higher than on a leaf without a droplet. However, the variation was rather great, $\pm 1.8^\circ\text{C}$ at the 95% confidence interval. The strong variation was probably, at least partly, due to inexact position of the sensor within the droplet, in which a great temperature gradient was supposed to exist. At the peripheral position the temperature anomaly was greatly reduced, and no longer significant; 0.4°C (± 0.8). The temperature rise in the center of water droplets might be a result of the refraction effects being dominant over the evaporative cooling. Laterally under the water droplets the radiation is reduced due to an increased reflection. This effect together with evaporative cooling might have caused a lower temperature in this part of the droplet.

Under the Betanal droplets the temperature was lower than under the exposed leaf, -1.5°C (± 0.8). The temperature reduction under the Betanal droplet might be a result of both shading effects of the opaque droplet and an evaporative cooling.

It should be mentioned here that this analysis is based on water droplets that are more or less semispherical. At a normal overhead irrigation, so much water is added that a water film is created on the plants and no effect of radiative concentration due to refraction therefore occurs. The evaporative cooling of leaf surfaces, after overhead irrigation, will therefore instead reduce the leaf temperature. This is shown by Lomas et al (1972),

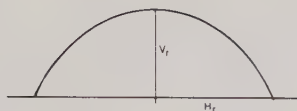


Figure 6.7. The vertical (V_r) and horizontal (H_r) radiuses of a semispherical water droplet.

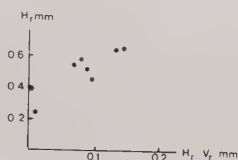


Figure 6.8. Received relation between droplet size and the differences between vertical and horizontal radiuses.

where the leaf temperature of an overhead irrigated potato crop was reduced $10-12^{\circ}\text{C}$.

6.2.5 Soil Temperature

In the figure 6.9 the surface-close soil temperatures near a plant are presented. During daytime in early July, at the depth of 3 cm, on average it was $3-4^{\circ}\text{C}$ warmer at the unsheltered soil between two rows, than right under a row with beet plants. In nighttime it was about 0.5°C cooler in the unsheltered soil. These horizontal soil temperature differences also create horizontal temperature differences in the air near the ground surface, which is seen in figure 6.10. The effect of the non-symmetrical shading to the east and to the west of the rows, is indicated in figure 6.9. 10 cm to the east of the row, at the depth of 3 cm, the temperature rose normally in the morning, but declined very rapidly in the afternoon. A similar result was recorded for the west side, but with a delayed and repressed temperature rise in the morning, and a normal development in the afternoon. In figure 6.11 is presented an interpolation of the received result, showing the daily change of the anomalies' spatial distribution. As seen in the figures 6.9 and 6.10, this surface-close temperature variation disappears later in the season.

In the deeper layer at -10 cm, even in the early period there were very small spatial temperature differences, see figure 6.12. At the depth of 20 cm, the soil temperature was probably more or less uniform.

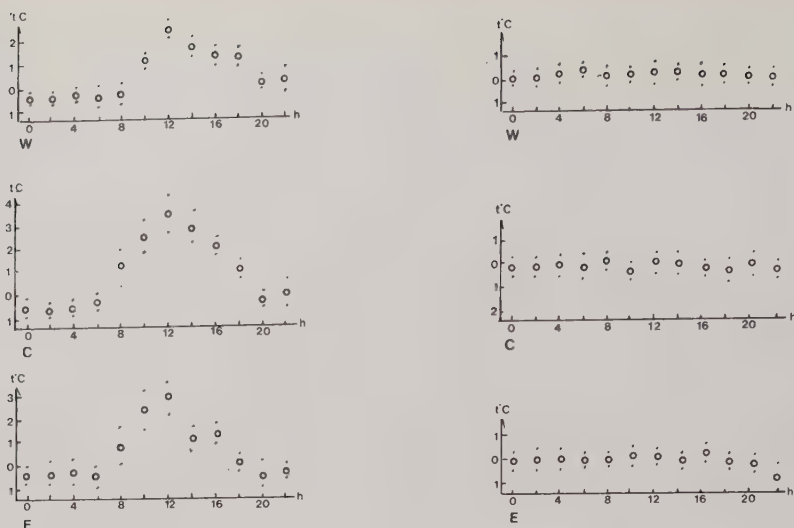


Figure 6.9 Average daily development of the temperature anomaly 3 cm under the soil surface in the space between two beet rows (C), 10 cm to the east of a row (E) and 10 cm to the west (W) of a row, in relation to the soil temperature 3 cm right under a row. The rows were all north-to-south oriented. The figures to the left are based on data from the period 1983.07.11-07.15 and the figures to the right from the period 1983.08.09-08.18. The 95%-confidence limits are marked.

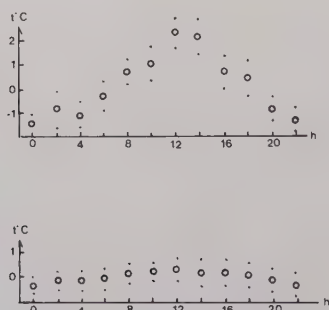


Figure 6.10. Average daily development of air temperature anomaly at 0.5 cm above the exposed soil, in relation to the air temperature at the same level within a beet row. Based on data from the periods 1982.07.15-07.22 (top) and 1982.08.16-08.25 (bottom). The 95%-confidence limits are marked.

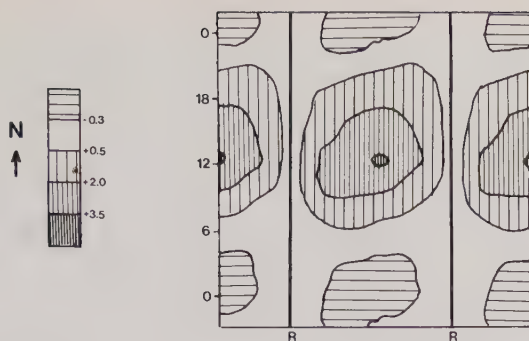


Figure 6.11. Interpretation of the spatial soil temperature variation during the day at 3 cm depth, under a non-closed beet stand. The positions of the north-to-south oriented beet rows are marked by the vertical lines. Based on data from the period 1983.07.11-07.15.

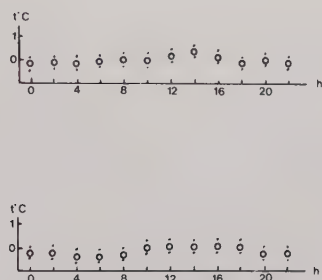


Figure 6.12. Average daily development of the temperature anomaly in the soil (at the depth of 10 cm) in the space between two beet rows, in relation to the temperature at the same depth under a beet row. Based on data from the periods 1983.07.11-07.15 (top) and 1983.08.09-08.18 (bottom). The 95%-confidence limits are marked.

The effect of shading from a plywood plate, 40*40 cm in size, at the depths -0.5 cm and -3 cm, studied in a separate experiment is presented in figure 6.13. It is seen that the effect of this shading was much greater than the shading of the beet stand, presented above. This difference was caused by two factors. First, in this experiment, a greater surface was covered; second, the plywood more completely prevented the incoming radiation. In spite of reduced radiative losses for the covered soil, the nighttime anomaly at this soil was not so great as in the daytime. This may be partly a result of a lag effect of the greater daytime energy input into the unprotected soil, but also caused by the shorter night.

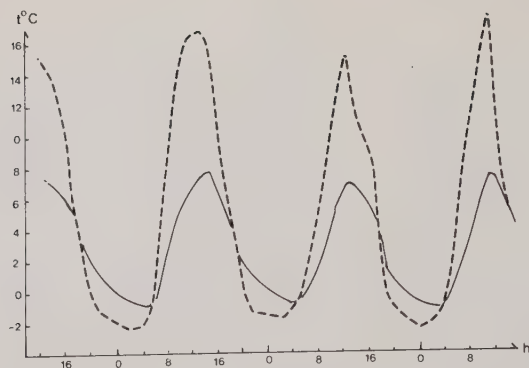


Figure 6.13. Differences in soil temperature between unsheltered soil (broken line) and a point at the same depth under a surface covered by a plywood plate, 40*40 cm in size (solid line). Based on data from July 19-22, 1982.

6.2.6 Net Radiation

Some studies have also dealt with the net radiation over and within the beet stand. In figure 6.14 is shown the net radiation over the beet stand and over bare ground measured in early July 1981 when the soil was completely dry, having a high albedo. At nighttime no differences are seen, but in daytime the net radiation was strongest over the beet stand due to a reduced outgoing radiation. Apart from the incoming shortwave radiation, the net radiation is affected by the albedo, heating coefficient of the surface and the long wave radiation. Stanhill et al (1966) showed that of all these factors, the albedo is of the most importance for the net radiation. Monteith (1959) studied the albedo change over a growing sugar beet stand. Here was seen that the albedo, due to an increased crop cover, initially did decline in May-June, from 0.18 to 0.14. After a period of constant low albedo in

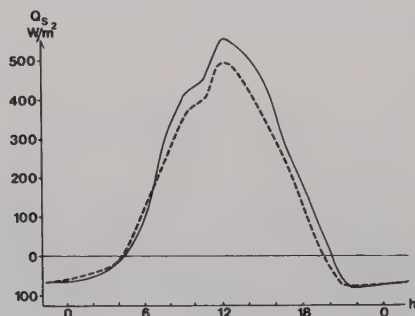


Figure 6.14. Net radiation above a beet stand (solid line) and above bare, dry soil (broken line), in July 8, 1981.

Table 6.1. Some albedo values of different soils, after Wijk & Scholte (1963).

Surface	Albedo
Dark clay, wet	0.02-0.08
Dark clay, dry	0.16
Sand, wet	0.09
Sand, dry	0.18
Bare fields	0.12-0.25
Wet plowed fields	0.05-0.14

the beginning of July, the albedo increased, reaching a maximum of 0.28 in late July. Still later, the albedo declined somewhat to 0.22 in late August. The rise in albedo was evaluated to be a result of the leaves getting more and more horizontally orientated, instead of the initial vertical position, the latter being more effective in trapping the radiation. Studies on single leaves showed an albedo of 0.26. Van Wijk & Scholte Ubing (1963) presented values of albedo over soils. Some of these are shown in table 6.1.

The lower albedo over the beet stand in early July, found by Monteith, in relation to the albedo of bare dry soil according to table 6.1, explains the recorded differences. Another factor that might increase the net radiation over a beet stand is the energy losses by transpiration. This reduces the temperature and by this the longwave radiation is repressed. Furthermore, energy in the beet stand is stored by photosynthesis. However, this demand is low. On a bright day at a high photosynthetic rate, the efficiency is only 3.2% (Jones 1983, p 160).

On August 27, 1983, when the stand was well closed, some measurements of the net radiation were done at different levels in the beet stand. The average net radiation above the stand at 13.00-13.35 was 512 W/m². Under single leaves sheltered from the direct sun radiation but exposed to the sky, the net radiation was 81 W/m². Under leaves covered also from diffuse radiation from the sky, the net radiation was still lower, 61 W/m². It should be said, though, that the variation over time, in spite of a clear sky, was very great.

6.3 WIND PATTERN

6.3.1 Methods

More detailed studies describing the plant-close wind movement were made on June 2, 1982, and on July 8, 1985, both during occasions when the wind was gentle and stable. The measurements were made in a area 20*20 cm in size surrounding a 7 cm and 10 cm wide plant in the four-leaf stage. In the vicinity of the examined area, there were no other plants. In 1982 the measurements were made only at the surface close level +1 cm, but in 1985 the level +5 cm was examined, too. This year some other detailed wind measurements close to the leaves were also done.

Due to the temporal wind fluctuations, after each crop-close wind measurement, it was necessary to measure the wind at a reference position, unaffected by the plant, in order to verify that the wind still was constant. If the wind had changed, due to a wind gust, the measurement close to the crop was omitted.

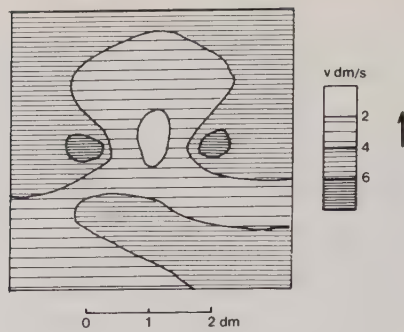


Figure 6.15. Wind velocity pattern, 0.5 cm above the ground at a single beet plant in the four-leaf stage, placed in the middle of the figure. The wind direction is marked by the arrow. On the basis of data from June 2, 1982.

6.3.2 Results and Evaluation

In both studies the unaffected wind at 1 cm above the ground was 0.3-0.4 m/s. In figure 6.15 is presented the wind velocity around the plant at the measurements in 1982. It is seen that the effect of single plants on the wind during the establishment is very narrow and only noticed at a distance closer than a few centimeters. 1 cm over the ground the wind was reduced the first centimeters to the lee of the plant. In the windward direction, too, the wind velocity was reduced, but here at a shorter distance. 5 cm from the plant at this level, an effect of the plant on the wind was noticed only to the lee of the plant. Some centimeters lateral of the plant at this level an increased wind velocity was noticed. The increased velocity is seen as a result of a concentration of the wind flow to the side of the plant.

5 cm above the ground, some 5 cm from the center of the plant close to the leeward and windward leaves, a decreased wind velocity was noticed, with a velocity of 0.2 m/s, to be compared with the general wind at this level of 0.5-0.6 m/s. The lateral leaves with their thin profile, faced a smaller area to the wind. Therefore they affected the wind only very close to the leaf. Some millimeters above the leaf surface the wind velocity was 0.2 m/s, but a centimeter from the leaf it was 0.4 m/s. In the center of the plant the wind velocity was slightly reduced, 0.3 m/s. 10 cm from the single plant no effect on the wind velocity was seen.

From these studies it is seen that the wind is affected only very close to single beet plants. However, in chapter 5 is seen that a beet stand, even if it is not closed, has a pronounced effect on the surface-close wind climate.

6.4 SUMMARY

Very close to the meristem the daytime temperature was slightly lower than the ambient air temperature. This reduction is probably caused by evaporation, but shading effects are also of importance.

At the leaves which were not shaded, during clear and calm weather in daytime, an increased temperature was noticed. This result corresponds to studies by others. However, according to the literature, a reduced temperature of the leaves could be seen during more cloudy and windy situations. This reduction is mainly caused by transpirative cooling.

Under water droplets, placed on a beet leaf, an even greater positive temperature anomaly was found during clear conditions. This increase is a result of the refractional concentration of rays to the leaf surface at the droplets' base.

The wind velocity was affected by single plants, too. The reduction in wind velocity was most intense on the lee side of the plant, but also seen at the windward side. Some centimeters lateral of the plant, the velocity was increased, due to tunnel effects.

7.1 INTRODUCTION

7.1.1 Background

Many studies have shown the effects of temperature on plant development, from seedling growth and emergence to final yield. These studies are usually carried out in growth chambers, under very controlled conditions. Most of the studies have shown an optimum response of the temperature on the development and final yield. When an optimum temperature was not found, this can be due to the fact that the both extremes, high and low temperatures, were not examined.

When comparing studies of this kind, it is of importance to know how the growth is measured: what relation or criteria for development is used? An increased growth of the green vegetative parts during a short period after emergence does not always improve the yield at harvest. The case could be the opposite if a crop ripens too fast and cannot use the possibility of growth late in the season. However, as these problems primarily not are of climatological interest, they will not be penetrated more thoroughly in the studies presented here.

Egli & Wardlaw (1980) showed an optimum seed growth rate for soybeans at a day/night temperature combination of 27/22°C. For corn growth Warrington & Kanemasu (1983) found a higher optimum temperature for emergence, with the fastest emergence at a daily mean temperature of 30°C. The minimum temperature for emergence was then 9°C. Also Pearson et al (1970) used a growth chamber with the temperature held at constant levels and showed an optimum temperature for cotton root elongation of 32°C. The effect was increased by low levels of soil strength and high pH (when raised from pH 4.6 to 6.2). Soil moisture, too, affects the percental emergence of an optimum response. This is shown by Bierhuizen (1973), among others. In a study by Wright et al (1978), however, several grasses and legumes grown in growth chambers with four different levels of soil moisture, ranging from 1/3 to 9 bars, showed a decreased and delayed emergence caused by increased soil water tension.

Furthermore, the development after emergence is affected by an optimum temperature. Nielsen et al (1966) demonstrated that for oats grown in a growth chamber, the optimum dry matter production of straw and grain was reached at a temperature of some 20°C. Concerning sugar beets Brown (1976, p 79) presents an optimum growth rate at a temperature of 20-25°C, and Stegman & Bauer (1977) stresses the importance of sufficient soil moisture during the growth, for reaching high beet yields.

Not only are the rate of growth and the yield affected by climatic variables but the morphology is also affected. In increased cold, the roots get thicker and less branched, possibly because of a reduced production of growth substances (Nielsen & Humphries 1966). Combinations of night and day temperatures can affect different parts of the plant in different ways (Thomas & Raper 1978), and often the root has a lower optimum growth temperature than the shoot (Morrow & Power 1979 and Nielsen & Humphries 1966). This relation is a result of a more rapid decrease of respiration than of assimilation, caused by reduced temperatures, which increase the net production of assimilate to support the

root growth (Heinonen 1970 and Bierhuizen 1973).

The growth response to climatic effects is, of course, different for different species, but is also dependent on the varieties (James et al 1978). The optimum temperatures may also differ between vegetative and reproductive growth, as well as differing according to the stage of development (Nielsen & Humphries 1966).

One can find many reasons for an optimum response to temperature. The main reason might be that the efficiency of the photosynthesis is reduced by decreased temperatures (Brouwer et al 1973 and Ray 1972, p 65). At higher temperatures the rate of respiration increases more rapidly, thus decreasing the net assimilation and repressing the growth (Yfoulis & Fasoulas 1978).

The water uptake is increased by raised temperatures. One reason for this is that the viscosity of water decreases with increased temperature, which increases the capillary diffusion rate of water flowing into the plant. The active uptake of water is also increased by a raised temperature, as well as the water transport through the root system (Nielsen & Humphries 1966, Dalton & Gardner 1978 and Ehrler 1963).

In addition, the uptake of various nutrients and their concentration in the plant increases with a raised temperature (Nielsen et al 1966, Ketcheson 1957 and Giordano & Mortvedt 1978). The phosphorus availability in the soil is affected by temperature in a rather complex way. The mineralization rate of organic phosphorus, as well as the chemical decomposition of insoluble inorganic forms of phosphorus, is increased by a raised temperature (Power et al 1964). Also the equilibrium concentration of phosphorus in solution is raised by higher temperatures. On the other hand the enlarged rate of immobilization and chemical fixation at higher temperatures reduces the phosphorus solubility (op cit). Thus the net result of a raised soil temperature depends on the relative rate of these processes. Furthermore, the release of nutrients from fertilizers is affected by soil temperatures (Nielsen & Humphries 1966).

Another temperature effect on crops is mentioned in a study by Rufty et al (1979) where it is shown that tobacco plants have a better tolerance against magnesium toxicity at higher temperatures. Finally could be mentioned the effect of the climate on the crop growth by means of the volatile losses of chemical insecticides, which are greater when wind velocity is increased and temperatures are raised (Harper et al 1982).

Rosenberg (1966) showed in a trial that windbreaks in the form of snow fences and rows of corn may increase the root and total weight of sugar beets. However, the sugar content at harvest was repressed by the snow fence. In Grace (1977, p 135-142) it is mentioned that the yield of sheltered crops usually is increased.

The aim of these studies was to evaluate how climatic variables under field conditions affects the growth of a sugar beet stand during different phases of the establishment. During the first period of the establishment the sugar beet is very sensitive to different climatic stresses; later in the season, as is seen in the southern parts of Sweden, the crop is quite insensitive to these stresses.

7.1.2 General Methods

The field investigations were made during the three years 1982-1984. During the periods 82.03.29-05.20 and 83.05.04-06.04, beet seedlings (Primahill) were sown twice a week in three (1982) or four (1983) blocks, respectively. In 1984, during the period 84.04.02-05.25, sowing took place only once a week. This year the trial was repeated in six blocks, with two different fertilization treatments. In one series 65 kg of nitrogen fertilizers were added per acre just before sowing, in the other series 1/3 of this amount was added before sowing and 2/3 when the plants had reached the 4-6 leaf stage. The plots were harrowed once in the beginning of the seasons. Immediately before sowing, where a manual seeder of the type Monocentra was used, the soil was loosened by raking. In 1982 some 25 seedlings were sown in each row; in 1983 and 1984 some 55 seedlings were sown in each row. The row length was in 1982 4 m and in 1983 as well as in 1984 10 m. The growth was measured in terms of the number of days needed for emergence and the percental rate of emergence, the speed of the shoot development during the first period after emergence and the final root weight at harvest. The studied climatic variables were temperature, soil moisture, wind velocity and net radiation. Also the differences between night and day situations were examined. When evaluating the results one must be aware of the fact that if an optimum daytime temperature during growth, happened to coincide with an unfavourable nighttime temperature, the two opposite effects of these temperatures might cancel each other. In order to avoid such an error at a field experiment, the experiments have to be repeated many times.

As before the 95% confidence interval was used in general in the statistical analyses.

The air temperatures were measured with a resistance Pt 100 thermometer placed in a white painted instrument hut. The soil temperatures were measured by a thermocouple at the depth of 5 cm. In chapter 2 is the used equipment presented more carefully.

7.2 CLIMATIC EFFECTS ON EMERGENCE

7.2.1 Days Needed for Emergence

7.2.1.1 Results

The received correlations between number of days needed for a 50% emergence of the final stand and the climatic situations during this period, are presented in the tables 7.1-7.3. The climatic variables examined in 1982 were mean air temperature (+1.75 m), soil temperature (-5 cm), net radiation and wind velocity (+5.0 m), daytime (8 h-18 h), and nighttime (20 h-4 h), as well as the cumulative net radiation during the day and the daily extremes and mean of air temperatures. In 1983 only the daily extremes and mean air temperatures were studied. Finally in 1984 these variables as well as the daily mean soil temperature were examined. In all the three years the soil water tension at -10 cm was examined. Figures 7.1-7.4 show some of the relations.

Table 7.1. Coefficients of correlation (r) with the 95% significant levels and regressions (k), received from linear regressions between days needed for a 50% emergence of the final stand, and contemporary climatic variables, according to the formula $y=l+kx$. Based on data from 1982. Consult also the text.

	r	k
Air temperature, day	-0.91+/-0.10	-2.2
Soil temperature, day	-0.94+/-0.07	-2.2
Net radiation, day	+0.25+/-0.54	+1.0*10 ⁻¹
Wind, day	+0.77+/-0.23	+4.9
Cumulative net rad., day	+0.00+/-0.00	+4.0*10 ⁻³
Air temperature, night	-0.96+/-0.05	-2.4
Soil temperature, night	-0.96+/-0.05	-1.9
Net radiation, night	-0.74+/-0.26	-7.2*10 ⁻¹
Wind, night	+0.84+/-0.17	+7.3
Air temperature, max.	-0.95+/-0.06	-2.7
Air temperature, min.	-0.96+/-0.05	-2.2
Air temperature, mean	-0.76+/-0.24	-3.3

Table 7.2. Same as table 7.1, but data from 1983.

	r	k
Air temperature, max.	-0.94+/-0.12	-2.9
Air temperature, min.	-0.85+/-0.28	-1.4
Air temperature, mean	-0.91+/-0.17	-1.7

Table 7.3. Same as table 7.1, but data from 1984.

	r	k
Air temperature, max.	-0.26+/-0.26	-1.6
Air temperature, min.	-0.36+/-0.25	-1.9
Air temperature, mean	-0.28+/-0.26	-1.6
Soil temperature, mean	-0.29+/-0.26	-1.2

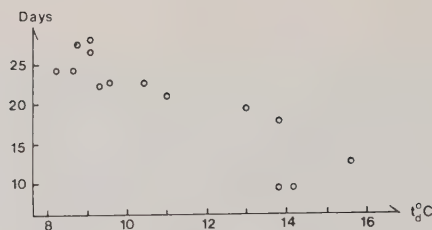


Figure 7.1. Relation between number of days needed for a 50% emergence of the final stand, and the mean daily air temperature between 08 and 18 h, during this period. The plot is based on data from 1982, where each dot represents the average for the three blocks, sown on the same date.

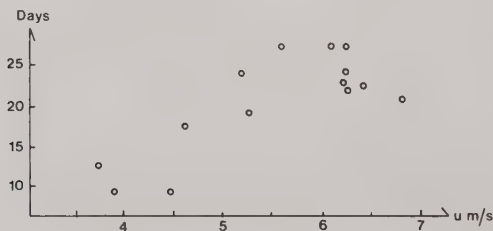


Figure 7.2. Relation between number of days needed for a 50% emergence of the final stand, and the mean daily wind velocity between 08 and 18 h, during this period. The plot is based on data from 1982, where each dot represents the average for the three blocks, sown on the same date.

The correlations between different temperature variables and number of days needed for emergence were very strong for the years 1982 and 1983, with coefficients of correlation greater than 0.90 (compare with figure 7.1). An increase in nighttime or daytime temperature of one degree was connected to a roughly two-day decrease in time needed for emergence. A corresponding effect was also found for the daily extreme temperatures. A correlation between daytime net radiations, (both accumulated positive and daily mean between 08-18 h) was absent, which is surprising. A negative correlation was found between nighttime radiation and days needed for emergence. There exists a strong correlation between wind velocity and days needed for emergence (figure 7.2). From figure 7.3 is seen that in 1982 and 1983 the seedlings; in general, emerged faster in wetter condition. In 1984 no correspondence could be found between days for emergence and soil moisture.

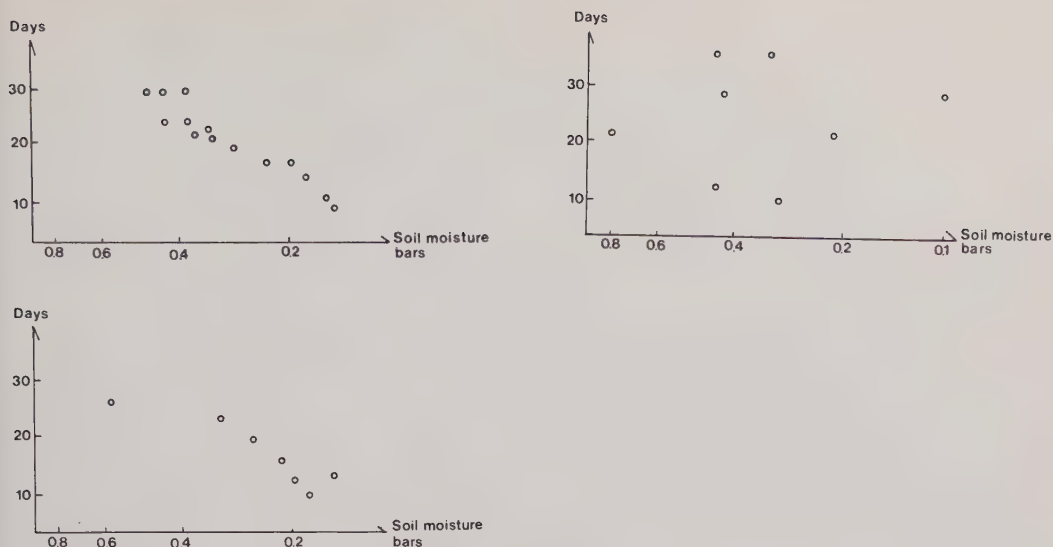


Figure 7.3. Relation between number of days needed for a 50% emergence of the final stand, and the average soil moisture content, in bars, during this period. The plot is based on data from 1982 (top left), 1983 (bottom) and 1984 (top right), where each dot represents the average for all blocks, sown on the same date.

7.2.1.2 Evaluation

The shortened period of emergence at higher temperatures is evident a result of increased metabolism, supported by a more effective uptake of water and nutrients in a warmer environment. Studies by others have also given the same result. Compare with the introduction of this chapter. No negative effect of high temperatures is evident. However, figure 7.4 indicates that even in a very warm environment, the seedlings still need not less than ten days or more for emergence.

The covariation between the length of the period for emergence and nighttime net radiation, is seen as a result of the correlation between temperature and net radiation, and not as a direct relationship. The correlation between wind and emergence period is somewhat more unexpected. However, this also might be an indirect relationship, resulting from stronger winds in cloudier days. For nighttime conditions, it might be more difficult to explain this relation.

In 1983 and 1984 the study dealt only with daily minimum, maximum and mean temperatures, and soil moisture content. The result from 1983, concerning the temperature, was quite similar the result from the previous year. However, in 1984 the result did differ some. In figure 7.4 is seen that some samples (marked 1) needed a very long period for emergence, some thirty to forty days, in spite of a relatively high temperature. These samples were sown

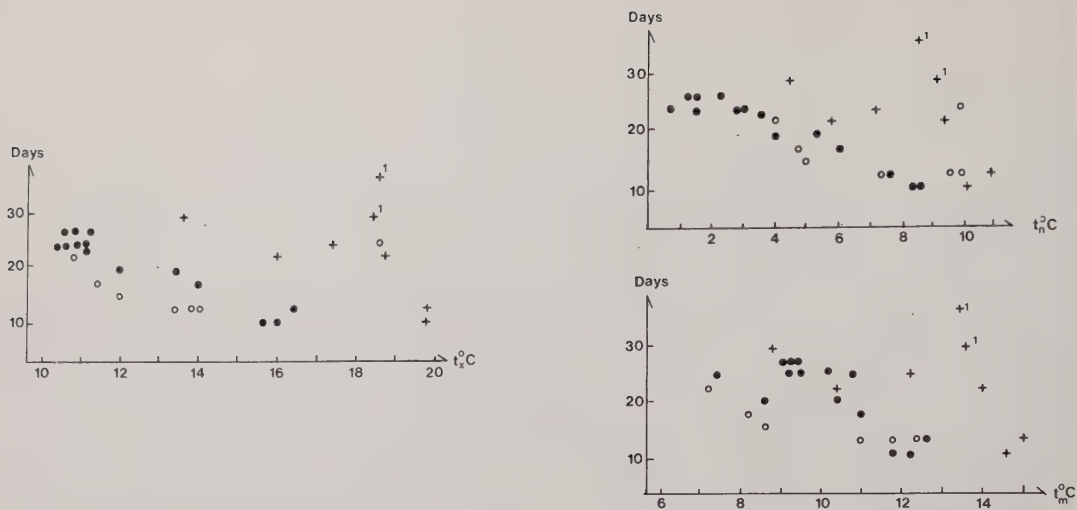


Figure 7.4. Relation between number of days needed for a 50% emergence of the final stand, and the daily maximum (left), minimum (top right) and mean temperature (bottom right). The plot is based on data from 1982 (●), 1983 (○) and 1984 (+). 1 indicates the samples in 1984 which were sown under very dry conditions.

in late April and the first two weeks of May, and had to develop in a period with no rain and insufficient soil water. When the rain finally fell, the seedlings sown during this dry spell all began to develop and emerged almost simultaneously. However, in spite of this, a weak correlation between the temperature variables and emergence is noticed (r roughly 0.30). If one omits data from this dry period, the correlation increases to 0.89, which corresponds with the previous years (table 7.4).

In table 7.5, and figure 7.4, are presented the correlations between mean and daily extreme temperatures for all the three years versus days needed for emergence. The correlation of minimum temperature is numerically stronger than the correlation of maximum temperature, as well as the effects being greater, indicating higher gain in higher nighttime temperatures. However, no significant differences could be noticed.

7.2.2. Percental Emergence

Correlations from the three years between average mean temperature and percental emergence are presented in figure 7.5. In the figure it can be seen that in 1984 there was a good agreement between these variables, but that the same good correlation was not found the previous years. However, a chi-two test, based on data from all three years, confirms this relationship at the 95%-level of confidence.

Table 7.4. Like table 7.3, but data from the dry spell is excluded.

	r	k
Air temperature, max	-0.89+/-0.08	-2.8
Air temperature, min	-0.89+/-0.08	-2.6
Air temperature, mean	-0.89+/-0.08	-2.7
Soil temperature, mean	-0.89+/-0.08	-1.8

Table 7.5. Like table 7.1, but based on data from all the three years 1982-1984. As in table 7.4, data from the dry spell in 1984 is excluded.

	r	k
Air temperature, max	-0.58+/-0.25	-1.4
Air temperature, min	-0.77+/-0.15	-1.7
Air temperature, mean	-0.70+/-0.19	-2.4

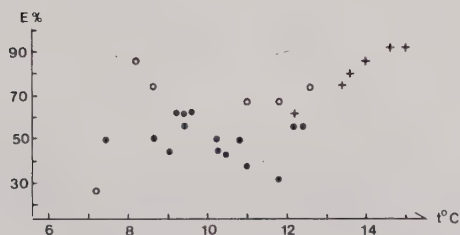


Figure 7.5. Relation between percental emergence for the three years 1982 (●), 1983 (○) and 1984 (+), and average daily mean temperature before emergence. Each dot represents the average relation for all blocks, sown on the same date.

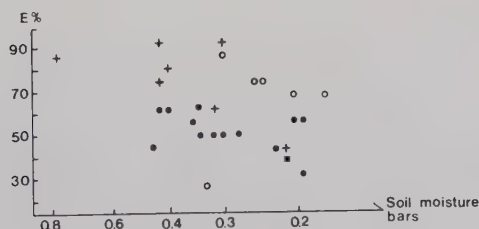


Figure 7.6 Relation between percental emergence for the three years 1982 (●), 1983 (○) and 1984 (+), and estimated average soil moisture tension, in bars, before emergence. Each dot represents the average relation for all blocks, sown on the same date.

The correlation between soil moisture and percental emergence, differs from the correlation to days needed for emergence. As is seen in figure 7.6, an increased soil moisture content in general decreased the percental emergence. This result should be compared with the results dealing with days for emergence. The final effect of soil moisture, received from these two studies, could be that if the soil is very wet, only those seedlings will survive which because of different reasons (genetical) emerge fast and the rest will decay, perhaps as a result of shortage of oxygen. If the soil water content is low, the seedlings will need a longer period for emergence, but the rate of emergence will only be affected slight.

7.3 DEVELOPMENT AFTER EMERGENCE

7.3.1 Introduction

As was stated in the background to this chapter, many studies have dealt with the problem of how climatic variables, mainly temperature, but to some extent also soil moisture, affect the growth of different crops. Most of these studies have been done in growth chambers under artificially controlled conditions. The present study is based on field conditions which gives the advantage of a realistic environment during the growth of the crop. The problem with this kind of study is interference of other variables, both of climatological and agronomical characters.

7.3.2 Methods

From emergence until the plants reached the four-leaf stage the average levels of development were estimated for each row. This was made on the basis of a method developed and used at the Agricultural Engineering Department at the Swedish Sugarbeet Company in Staffanstorp, where 0.1 represents the stage when the cotyledons are just visible; 1.0 the first pair of leaves are visible; 1.5 the first pair of leaves are of the same size as the cotyledons; 2.0 the second pair of leaves are visible; 2.5 these leaves have the same size as the first pair, etc. The rate of development between two estimations of stages, was determined as the daily change of these stages, during this period.

In 1982 the rates of development were correlated to: the contemporary mean air temperatures (+1.75 m); mean soil temperatures (at -5 cm), mean net radiations; mean wind velocities (+5.0 m), daytime (8 h-18 h), and nighttime (20 h-4 h), respectively; and soil water tension at -10 cm. In 1983, the development was only compared to average mean and extreme temperatures, and soil moisture at -10 cm. For 1984, finally, correlations were made between the development and again those variables analysed in 1982.

7.3.3 Results and Evaluation

In figure 7.7 is presented the development of the different rows in 1982. One might notice the fairly low rate of development until May 14, and the two periods of higher rates of development, May 24-28 and the first days of June. Until May 14 the weather

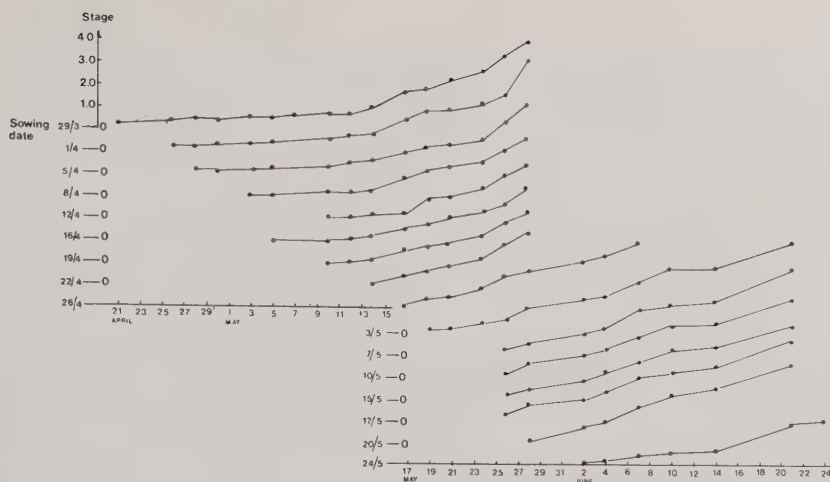


Figure 7.7. The average stages of development for the different sowing dates during the establishment in 1982. Note that the x-axis for each sowing date is stepwise moved down, and that the y-axis also should be lowered to the level of the actual sowing date. Consult also the text.

was cold, and only after this date did the daily minimum temperatures first exceed 8°C . Also the periods with a positive anomaly of the rate of development, correspond to an anomaly in temperature that is positive this time. Apart from these anomalies, the rate of development is fairly constant, with only smaller variations.

All the climatic variables, except soil moisture and temperature in 1982, show at the 95% significant level, a normal distribution; most of these variables show also at the 99% level a normal distribution. The temperatures in 1982 show only at the 90% significant level a normal distribution. The relations to the soil moisture content were examined by chi-two tests. The rates of development have for all the three years a skewed distribution; after a square-root transformation also this variable shows at the 99% significant level a normal distribution. In the further analyses and plottings, this transformed value describing the rate of the development is used.

The results of linear regressions between the transformed values of development rate and climatic variables, are presented in table 7.6. Plots between temperatures and rate of development indicates an optimum response, see figure 7.8. Thus regressions based on polynomial equations were also made. The results from these regressions are presented in table 7.7.

In general, the correlations between different temperature variables and the rate of development are strong, especially in the polynomial regression. The polynomial regressions show the best fitness for 1982, but for 1984 the fitness is also very good. In 1983 the soil moisture conditions were very troublesome, which might have degraded the correlation between growth and tempera-

Table 7.6 Coefficients of correlation, (r), with the 95% confidence limits, and regression (k), received from linear regressions between the square root rate of development, and some contemporary climatic elements, according the formula $y=1+kx$.

		r	k
Air temperature, max	1982	-	
	1983	0.34+/-0.18	$+1.4 \cdot 10^{-2}$
	1984	0.52+/-0.17	$+1.9 \cdot 10^{-2}$
Air temperature, min	1982	-	
	1983	0.26+/-0.19	$+2.0 \cdot 10^{-2}$
	1984	0.59+/-0.15	$+1.5 \cdot 10^{-2}$
Air temperature, mean	1982	-	
	1983	0.58+/-0.18	$+4.4 \cdot 10^{-2}$
	1984	0.62+/-0.14	$+2.2 \cdot 10^{-2}$
Air temperature, daytime	1982	0.49+/-0.16	$+1.2 \cdot 10^{-2}$
	1983	-	
	1984	0.55+/-0.16	$+2.2 \cdot 10^{-2}$
Soil temperature, daytime	1982	0.53+/-0.15	$+1.4 \cdot 10^{-2}$
	1983	-	
	1984	Too little data	
Net radiation, daytime	1982	-0.00+/-0.21	$-1.2 \cdot 10^{-4}$
	1983	-	
	1984	-0.00+/-0.23	$-1.3 \cdot 10^{-4}$
Wind, daytime	1982	-0.58+/-0.14	$-5.0 \cdot 10^{-2}$
	1983	-	
	1984	0.00+/-0.23	$+1.3 \cdot 10^{-2}$
Acc. net radiation, daytime	1982	-0.00+/-0.21	$-1.7 \cdot 10^{-5}$
	1983	-	
	1984	-	
Air temperature, nighttime	1982	0.63+/-0.11	$+2.9 \cdot 10^{-2}$
	1983	-	
	1984	0.66+/-0.14	$+1.9 \cdot 10^{-2}$
Soil temperature, nighttime	1982	0.57+/-0.13	$+1.8 \cdot 10^{-2}$
	1983	-	
	1984	Too little data	
Net radiation, nighttime	1982	-0.07+/-0.18	$-7.8 \cdot 10^{-4}$
	1983	-	
	1984	0.61+/-0.15	$+3.1 \cdot 10^{-3}$
Wind, nighttime	1982	-0.05+/-0.18	$-1.2 \cdot 10^{-2}$
	1983	-	
	1984	0.17+/-0.23	$+2.3 \cdot 10^{-2}$

Table 7.7 Coefficients of explanation (R^2), the significant level of the relation not being coincidental (based on factor analyses) (P), and coefficients of regression (k_1 , k_2) received from polynomial regressions between the square root rate of development, and some contemporary temperature variables, according to the formula $y=1+k_1x+k_2x^2$. Also the optimum temperatures, based on derivations of these polynomial functions, are shown (opti).

	Year	R^2	P	k_1	k_2	opti
Air temperature, max.	1982					
	1983	0.15	95	$+6.7 \cdot 10^{-2}$	$-1.5 \cdot 10^{-3}$	22
	1984	0.30	99	$+7.9 \cdot 10^{-2}$	$-1.7 \cdot 10^{-3}$	23
Air temperature, min.	1982					
	1983	0.26	90	$+4.3 \cdot 10^{-2}$	$-1.3 \cdot 10^{-3}$	16
	1984	0.35	99.9	$+2.8 \cdot 10^{-2}$	$-7.5 \cdot 10^{-4}$	19
Air temperature, mean	1982					
	1983		Too little data			
	1984	0.41	99.9	$+7.2 \cdot 10^{-2}$	$-1.9 \cdot 10^{-3}$	19
Air temperature, day	1982	0.48	99.9	$+8.1 \cdot 10^{-2}$	$-1.9 \cdot 10^{-3}$	21
	1983					
	1984	0.33	99.9	$+8.4 \cdot 10^{-2}$	$-1.9 \cdot 10^{-3}$	22
Soil temperature, day	1982	0.50	99.9	$+8.6 \cdot 10^{-2}$	$-2.2 \cdot 10^{-3}$	20
	1983					
	1984		Too little data			
Air temperature, night	1982	0.62	99.9	$+1.3 \cdot 10^{-1}$	$-5.2 \cdot 10^{-3}$	12
	1983					
	1984	0.39	99.9	$+3.6 \cdot 10^{-2}$	$-8.9 \cdot 10^{-4}$	20
Soil temperature, night	1982	0.50	99.9	$+8.1 \cdot 10^{-2}$	$-2.1 \cdot 10^{-3}$	19
	1983					
	1984		Too little data			

ture. As with days needed for emergence, the nighttime temperatures show numerically a better correspondence with the development than the daytime temperatures. From the linear regressions it is seen that in general, there has been a numerically greater response to changes of the nighttime temperature, than to the daytime temperature. However, neither of these differences are significant. No greater differences could be found between air and soil temperatures either; these variables are, of course, highly correlated to each other.

Derivations of the polynomial formula describing the relations in 1982 (the year covering the widest range of temperatures and having high as well as low temperatures repressing the growth) indicates a daytime and nighttime optimum temperature of 21°C and 12°C , respectively. The daytime and nighttime minimum temperatures below which all growth was inhibited were 6°C and 4°C , respectively; corresponding maximum daytime and nighttime temperatures above which all growth will be inhibited were 37°C and

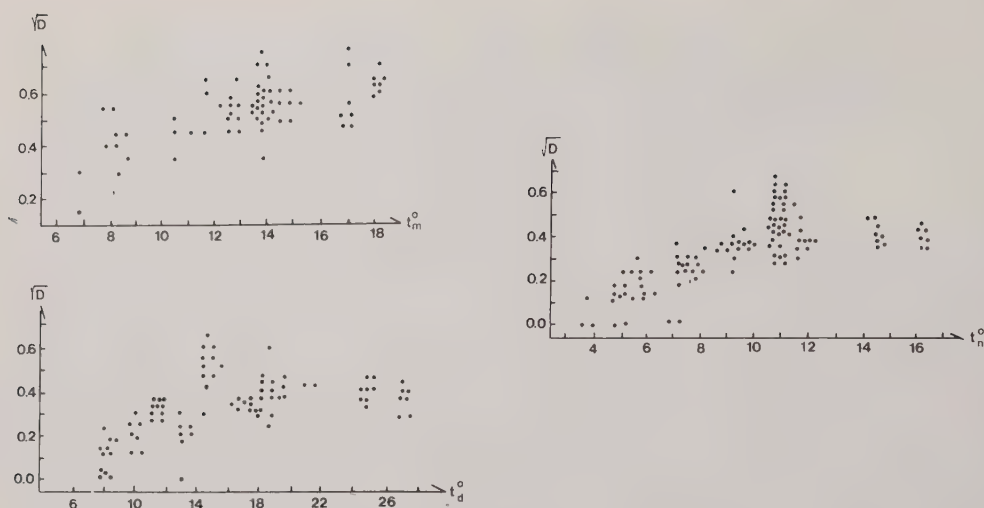


Figure 7.8. Relation between the square root rate of development versus daily mean temperature in 1984 (left), daytime mean temperature in 1982 (bottom) and nighttime mean temperature in 1982 (right).

Table 7.8. Coefficients of explanation (R^2), and regression (k_1 , k_2) with the 95% confidence limits, describing the polynomial relation between the square root of development rate and daily mean temperature, according the formula $y=1+k_1x+k_2x^2$. Based on data from the stages 1-2 and 3-4, respectively. Also the optimum temperatures, based on the received constants, are marked.

Stage	R^2	k_1	k_2	opti
1.0-2.9	70.1	$+7.4 \cdot 10^{-2} \pm 9.8 \cdot 10^{-3}$	$-1.8 \cdot 10^{-3} \pm 2.8 \cdot 10^{-4}$	21
3.0-4.9	22.1	$+5.2 \cdot 10^{-2} \pm 2.5 \cdot 10^{-2}$	$-1.2 \cdot 10^{-3} \pm 5.5 \cdot 10^{-4}$	22

21°C. These minimum, optimum and maximum temperature values, will surely vary with other factors, as for instance, soil moisture (see below), nutrient status, rate of evaporation among others. It should be stressed that these temperatures are due to an extrapolation, based on the regression constants, and can thus be seen only as a rough estimate; compare also figure 7.8, in which is seen the great variability of the relation.

In 1982, the mean square root rate of development was 0.32, which corresponds to mean daytime and nighttime temperatures of 13°C and 9°C, respectively. An increase of these temperatures by 1°C, has resulted in a 9% increase of the rate of development.

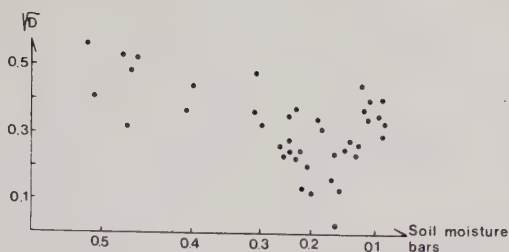


Figure 7.9. Relation between the the square root of development in 1982 and contemporary soil moisture content at the depth of 10 cm, in bars.

No greater differences in the relationship of mean daytime temperature and development were found between the first period after emergence (until the plants reached the two-leaf stage) and the following stage (until the plants reached the four-leaf stage). The optimum temperature was for both samples around 21°C, even if the correlation was stronger for the younger plants, see table 7.8. This can be seen as a result of the plants having a more uniform response to the climate during the first period after emergence. Later other factors interfere with this response, even if the values of the regression constants describing the response to temperature during the two periods could not be separated.

From the data of 1984 a relation is found between outgoing net radiation at nighttime and development. This is probably a result of correlations between radiation and temperature. The daytime incoming net radiation does not seem to have affected the growth directly, indicating that this variable was not acting as a limiting factor on the growth. The daytime wind shows in 1982 a significant correlation to the development, with a lower rate of development at higher wind velocities. This could be caused by the same accidental relationship as was mentioned concerning the emergence, where higher wind velocities were linked to a lower temperature and thus to a lower rate of development.

Chi-two analyses based on data from all three years have shown that the soil water content at 10 cm depth was negatively correlated to the rate of development (figure 7.9). This might be surprising, but in neither of the years were there any longer periods of dry spells, when the soil also in layers deeper than harrowing depth has dried out thoroughly and thus stressed the plants. Instead, the roots most of the time reached well-moist soil. However, in the later years some drier periods with lower rates of development could be found, indicating an optimum response, with the highest rate of development at a surface-close water tension between 0.9 and 0.25 bar.

Estimations of the temperature dependence at different soil*water situations, indicate another import aspect of the soil moisture variable (table 7.9 and figure 7.10). In 1982, at a soil moisture tension lower than 0.2 bar, the optimum daytime temperature was 23°C. At a soil moisture tension higher than 0.2 bar, this opti-

Table 7.9. Coefficients of explanation (R^2) describing the relation between the square root of development rate and daily mean temperature, at different soil moisture levels. Also the optimum, and extreme temperatures, based on the received regression constants, are marked.

	R^2	Min	Max	Opti
1982, soil tension >0.2 bars	0.69	8	23	15
<0.2 bars	0.58	6	40	23
1984, soil tension >0.4 bars	0.39	2	30	16
<0.4 bars	0.25	0	47	23

imum temperature was 15°C. At both levels of soil moisture, the minimum temperature for growth was around 7°C, but the maximum temperature for growth was much higher when the soil was moist. Extrapolations of these circumstances gives the values for maximum temperatures, 22°C and 39°C. It should be noted though that the higher, although not significantly higher, maximum rate of development in the dry conditions seen in figure 7.10, corresponds with the result from the chi-two analysis indicating a higher rate of development, in drier situations. An analysis based on the very few, very dry situations, indicates both a lower maximum rate of development and a lower optimum temperature. This indicates too, an optimal response to soil moisture. It should be stressed though, that this analysis was made on very little data, this could be one of the reasons why significant differences could not be found.

Similar results were received for 1984, too, when the material was classified into moist and dry situations, depending on if the soil water tension was higher or lower than 0.4 bar (table 7.9). The optimum temperatures were for the two classes 23°C (moist) and 21°C (dry). Again there was a very great difference between the extrapolated maximum temperatures, 47°C and 30°C, respec-

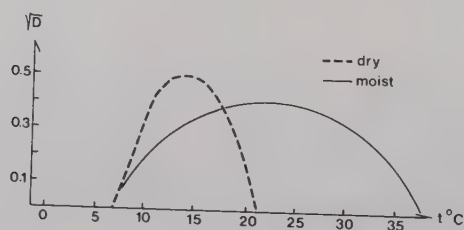


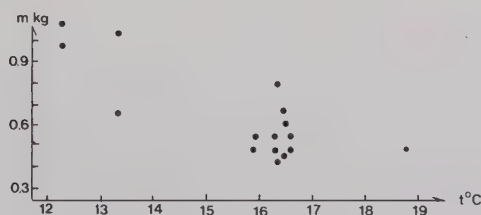
Figure 7.10. Received relations between square root of development and daytime temperature at a soil moisture tension at the depth of 10 cm, greater than 0.2 b (dry), and lower than 0.2 b (moist). Based on data from 1982.

tively. The differences were smaller for the extrapolated minimum temperatures, 2°C and 0°C. Of course there is a great uncertainty in these temperature values, especially those received by extrapolations.

7.3.4 Conclusions

7.4 EFFECTS OF THE CLIMATIC CONDITIONS DURING ESTABLISHMENT ON FINAL YIELD

Of ultimate interest when studying the climatic impact on the sugar beet growth is the climate's effect on the final yield, since this will indicate the potential economic benefit of different techniques which modify the climate at establishment.



7.4.2 Methods

Unfortunately the yield was measured in different ways in each of the three years. In 1982 all beet roots in the 16 rows and the three blocks, with different dates of sowing, were weighed individually. Correlations were made between the weight of the roots weighing more than 300 g and the climatic situations during different periods of the establishment. In 1983 all the plants from each row were weighed together, thus was the number of cases was reduced radically to roughly 15. Finally in 1984 the average root weight, and the total yield per acre, as well as the number of plants per acre, were calculated for each row. Correlations were made by regressions and chi-two analyses between the yield and climatic conditions during different stages of the establishment.

7.4.3 Results and Evaluation

The impact of the temperature at establishment on the final yield, presented in table 7.10, did differ the three years. In 1982, in general, a higher temperature was linked to a higher root weight at harvest, with the greatest climatic impact just at the time of emergence. In 1983 and 1984 a negative correlation existed between the temperature in spring and the final root weight; consult figure 7.11.

Figure 7.12, showing the relation between the temperature before emergence in 1982 and the final root weight, indicates an optimum response, with an optimum temperature of some 10-12°C. However, a factor analysis did not confirm this indicated relation.

The negative correlation could be explained by a greater loss of plants during a cold situation at the establishment. Those plants which emerged during this cold situation, and survived, could then grow bigger because of less competition from other plants. Another explanation of this result could be that the lower temperature in spring has caused a relatively greater root growth (compare with Morrow & Power 1979 and Nielsen & Humphries 1966). Later in the season, these plants with a greater root system might better withstand different stress situations, such as dry spells or an insufficient supply of nutrients. However, in 1984 the weather was not extremely dry, except during the first period of the establishment. One could therefore suspect that the former explanation is more adequate for this study. In 1982, the percentage rate of emergence at the different sowing dates varied only slightly in relation to the situation during the later years. This may be due to the fact that the rows were exposed to only smaller differences in competition, therefore those plants which succeeded in emerging in colder conditions, did not have the advantage of less competition, that the plants emerging in cold periods had the following years. This could explain why the negative correlation between root weight and temperature was not found in 1982, but in the two later years.

In 1982 and 1984, a higher content of soil moisture at the period of emergence was linked to a higher yield, measured both as root weight and number of plants at harvest (figure 7.13). In the data from 1983, the wettest year, and 1982 an optimum relationship was indicated by a maximum yield of root weight. Combining data from the three years, a maximum root yield per plant, was linked

Table 7.10. Coefficients of correlations, with 95% confidence limits marked, describing the recorded linear relations between different temperature variables during the establishment and root weight per plant at harvest. Note that the root weight has been calculated in different ways in each of the three years, consult the text.

1982	mean minimum temp, 1-10 days after sowing	+0.22+/-0.15
	mean maximum temp, 1-10 days after sowing	+0.06+/-0.16
	mean minimum temp, before emergence	+0.27+/-0.15
	mean maximum temp, before emergence	+0.18+/-0.16
	mean minimum temp, 10 days at emergence	+0.28+/-0.15
	mean minimum temp, 1-5 days after emergence	+0.30+/-0.15
	mean minimum temp, 1-10 days after emergence	+0.30+/-0.15
	mean maximum temp, 1-10 days after emergence	+0.25+/-0.15
	mean minimum temp, 5-15 days after emergence	+0.15+/-0.16
	mean minimum temp, 10-20 days after emergence	+0.06+/-0.16
	mean maximum temp, 10-20 days after emergence	+0.09+/-0.16
1983	mean minimum temp, 1-10 days after sowing	-0.82+/-0.05
	mean maximum temp, 1-10 days after sowing	-0.83+/-0.05
	mean daily temp, 1-10 days after sowing	-0.89+/-0.03
	mean minimum temp, 10-1 days before emergence	-0.87+/-0.05
	mean maximum temp, 10-1 days before emergence	-0.88+/-0.05
	mean daily temp, 10-1 days before emergence	-0.85+/-0.02
	mean minimum temp, before emergence	-0.90+/-0.03
	mean maximum temp, before emergence	-0.94+/-0.02
	mean daily temp, before emergence	-0.88+/-0.04
1984	mean nighttime temp, 0-5 days after sowing	0.00+/-0.82
	mean daytime temp, 0-5 days after sowing	0.00+/-0.82
	mean nighttime temp, 5-10 days after sowing	-0.71+/-0.20
	mean daytime temp, 5-10 days after sowing	-0.52+/-0.34
	mean nighttime temp, before emergence	-0.88+/-0.06
	mean daytime temp, before emergence	-0.88+/-0.06
	mean daily temp, before emergence	-0.90+/-0.05
	mean nighttime temp, 10-5 days before emerg.	-0.81+/-0.10
	mean daytime temp, 10-5 days before emerg.	-0.79+/-0.11
	mean nighttime temp, 5-0 days after emerg.	-0.71+/-0.15
	mean daytime temp, 5-0 days after emerg.	-0.66+/-0.18
	mean nighttime temp, 0-5 days after emerg.	-0.81+/-0.10
	mean daytime temp, 0-5 days after emerg.	-0.81+/-0.10
	mean nighttime temp, 5-10 days after emerg.	-0.57+/-0.23
	mean daytime temp, 5-10 days after emerg.	-0.24+/-0.40
	mean nighttime temp, 10-15 days after emerg.	-0.62+/-0.20
	mean daytime temp, 10-15 days after emerg.	-0.54+/-0.24

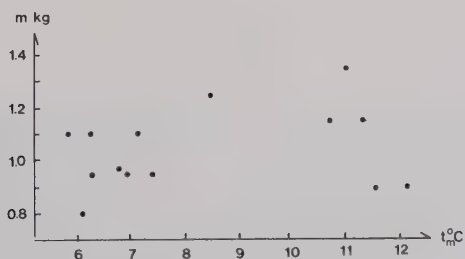


Figure 7.12. Relation between final root weight at harvest in 1982 and daily mean temperature before emergence. Each dot represents the average situation for each sowing date.

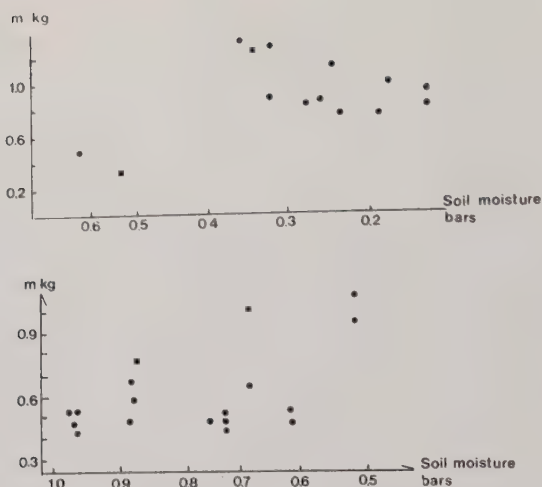


Figure 7.13. Relation between final rootweight in 1982 (top) and 1984 (bottom) versus soil moisture content at the depth of 10 cm, before emergence.

to at a soil moisture tension at -10 cm, before emergence of 0.5-0.3 bar (corresponding to 10-12% water by weight).

7.5 SUMMARY

The studies have shown that the temperature and soil moisture affects the growth of a sugar beet stand.

The number of days needed for emergence was, in general, reduced and the percental rate of emergence increased by a raised temperature before emergence. These relations were more or less linear, and a temperature rise of one degree has been linked to a faster emergence, accelerated by some two days. This is an important difference, as the plants usually emerge within three weeks. Concerning the soil moisture, it was noticed that dry spells delayed the emergence, but only to a minor extent has this variable affected the percental emergence.

The shoot development during the first period after emergence shows an optimum response to the contemporary temperature, with the highest growth rate at a mean daytime temperature of some 20°C, and a mean nighttime temperature of about 15°C. These relations were affected by the soil moisture, with wetter conditions giving higher optimum temperatures. The soil moisture, too, seems to have an optimum affect on the development after emergence, even though the water content during these studies usually was supraoptimum and an increased content of soil moisture has then repressed the growth. The highest growth rate was found with a soil moisture tension at 10 cm depth between 0.9 bar and 0.25 bar.

Regarding the yield (root weight per plant at harvest) both positive (in 1982) and negative (in 1983 and 1984) responses to an increased temperature were found. The advantage to a higher temperature in spring is a faster shoot development. On the other hand a lower temperature will stimulate the root growth (Morrow & Power 1979 and Nielsen & Humphries 1966). The relative benefits of a big root system or a well developed foliage, depend on the later appearance of dry spells, the supply of nutrients in the soil, etc. In general, increasing soil water content at emergence was found to increase the yield, both in terms of root weight per plant and plants per acre. The reduced competition in the event of a reduced plant number, caused by a cold period, resulted in bigger surviving plants. This can also explain the negative correlation between temperature and root yield. In 1983 an optimum response of final yield to soil moisture during the establishment was noticed, with the optimum water tension being 0.5-0.3 bar.

8 CLIMATIC EFFECTS OF SOIL STRUCTURE AND SOIL MANAGEMENT

8.1 INTRODUCTION

These studies, done in 1981-1984, try to evaluate how soil structures and different techniques in soil management can affect the micro climate at the germ and the seedling. The aim was to find possible ways to modify and optimize this climate. In general the most interest was given the temperature and soil moisture, but also other climatic elements as heat flux, wind velocity and evaporation were examined. The studied soil characteristics were aggregate sizes, compaction, soil moisture and influence of stones. The studied soil management techniques were harrowing, ploughless tillage, and the use of different sowing machines creating beds of different micro topography.

When evaluating the climatic effects of different treatments, comparisons were made to the situation at the same levels at a reference surface. Concerning the temperatures, the daily pattern of the difference received in these comparisons, called the anomalies, as well as the differences in daily mean temperatures were of interest. For the soil moisture, differences in water sorption and resorption were examined.

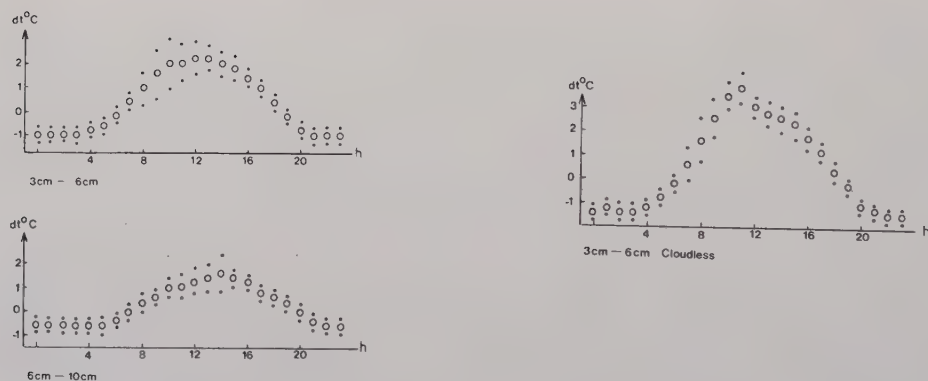


Figure 8.1. Mean hourly differences between soil temperatures of different depths. Data from the period 82.05.13-05.30. The 95%-confidence limits are marked. The diagram to the right refers to data only from "cloudless" conditions, with an estimated cloud cover of 2/8 or less.

In general, temperature was measured with thermocouples made of copper-constantan; each thermocouple having five sensors in parallel. The thermocouples for measurements of soil temperatures were made of 0.5 mm thick wires, and those for air temperature measurements of 0.03 mm thick wires. Measurements of temperatures were made every fifth minute, and hourly means were calculated. Some analyses were also made on how other climatic variables affect the temperature at different plots. For further information concerning the equipment used, see chapter 2.

No special study was made on the climatic effect of the sowing depth, even if many of the experiments also deal with this problem. This may be the easiest way to manipulate the climate at the germ. By reducing the daytime temperature and decreasing the nighttime cooling, an increased depth will give a reduced daily amplitude of temperature, see figure 8.1. This figure indicates also that the effect is most pronounced in shallow layers and at clear conditions. As there is a positive daily net radiation at the time of sowing and emergence in April-June, the daily mean soil temperature increases at a more surface close layer.

The changes in moisture content, too, are dampened by an increased depth. Especially the water sorption is slowed down. In figure 8.2 is shown the soil moisture content at different levels during a period in June, 1982.

The results from the different studies dealing with different techniques and soil structures are presented separately below.

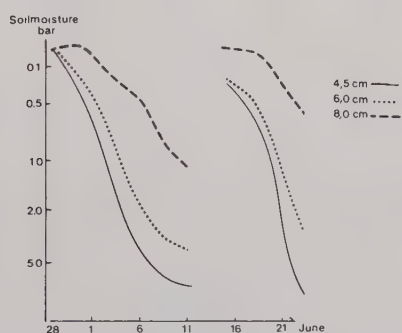


Figure 8.2. Moisture tension, in bar, at three sowing depths during two periods of sorption in June 1982.

8.2 EFFECTS OF AGGREGATE SIZE

8.2.1 Introduction

8.2.1.1 Background

Studies made by others have shown how the aggregate distribution of a soil affects the plant growth. Hammerton (1961) found that the emergence of beet plants was best in soils with a fine structure. This could be caused by a better moisture supply and lower mechanical impedance, compared to a more coarse soil. On the other hand Hagin (1952) showed a better plant growth in pots with a coarse soil; an insufficient supply of oxygen in the finer soils, is suggested as a possible cause of this. The studies presented here, carried out through the three years 1982-1984, deal with the climatic effects of soils with different aggregate structures.

8.2.1.2 The Plots

Soils with three different aggregate structures were constructed by sieving; one with aggregates >5 mm, one with aggregates <5 mm, and finally one with aggregates <2 mm. In the years 1982 and 1983 soil samples were taken in order to, by sieving, analyse the detailed distribution of the aggregates in each plot. Figure 8.3 shows that there was a slight redistribution of the soil structure after the primary sieving when the beds were made. In 1983 also the bulk density was determined; the most coarse structure was found to be the one with lowest density, see table 6.1. As only one sample was taken from each structure in this analysis, nothing can be said about the significance of the differences. However, a similar relation between the soil's bulk density and aggregate size was found by Abrol & Palta (1970). The increase in density of the two finer soils, is caused by a more dense stratification of a soil with a finer structure, whereas the finer aggregates fill the pore volume between the larger aggregates. Gumbs & Warkentin (1976) showed that the clod density of an aggregate increases by decreased size of the aggregates. The loss in porosity was evaluated as a result of the fact that the subdividing of larger aggregates mainly appears in fissures, which otherwise lowered the density of the bigger aggregates.

The measurements of climatic variables were made during the periods 1982.04.11-07.15, 1983.06.04-07.15 and 1984.05.05.09-06.23; the periods started immediately after the beds were formed. Concerning the weather during the periods, see chapter 1.

As the different structures in the surface layer were easily destroyed by rain, the analyses of the climatic effects were done on data from the first period after construction.

8.2.1.3 Methods

In the years 1982 and 1983 the temperature was measured on the firm bottom under a 6 cm thick cover of aggregated soil. In 1984 the temperature was measured on the firm seed bottom under soil covers of different thicknesses; 1 cm, 3 cm and 6 cm, respectively. This year the temperature was also measured at the same levels in compact, untreated soil.

Table 8.1. The bulk density (dry) of the three aggregate structures studied in 1983. For further information confer with the text.

Sample	<2 mm	<5 mm	>5 mm
Bulk density	1.14	1.05	1.01

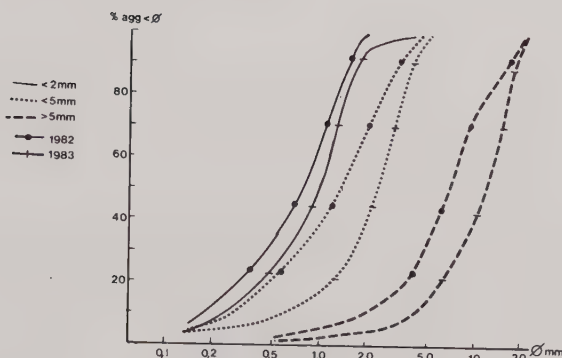


Figure 8.3. The accumulated aggregate distribution of the soils tested in 1982 and 1983. Soil samples were taken immediately after the beds were constructed.

In 1982 the soil moisture content on the seed bottom at 3 cm and 6 cm depth was measured almost daily with gypsum blocks. Soil moisture measurements were also made in the year 1984; this year the measurements were made on the firm seed bottom under a 3 cm thick layer of aggregated soil, and both on and in the seed bottom under a 6 cm thick layer of soil.

A relative value of the actual evaporation was obtained by weighing pans filled with a 5 cm thick layer of the three tested aggregated soils, placed outdoor and exposed to the same weather as the test plots. This year the soil moisture content was also measured at the bottom of 30 cm high columns filled with soil of different aggregate structures, and placed indoors during a period of both water resorption and following water sorption.

Besides different climatic variables, the emergence and plant establishment of the beet stand also were studied. Then it was found that a shallow bed with medium fine to fine aggregates in general gave the highest rates of emergence.

8.2.2 Results and Evaluation
8.2.2.1 Temperature, General

Results

This evaluation of the results is based on data from the periods 82.04.11-04.29, 83.06.04-06.30 and 84.05.09-06.03. Confidence limits are usually not presented in the text, the reader should here refer to the figures and tables.

In general at the 6 cm depth, a finer structure showed a greater daily temperature amplitude; see figure 8.4. In the year 1982 there was quite a big difference between the plots <2 mm and <5 mm; the former being 3.1°C warmer at noon, and 1.2°C cooler at midnight. This year the differences between the plots >5 mm and <5 mm were smaller, even if the greatest daily amplitude still was noticed at the plot with the finest structure. In 1983 there

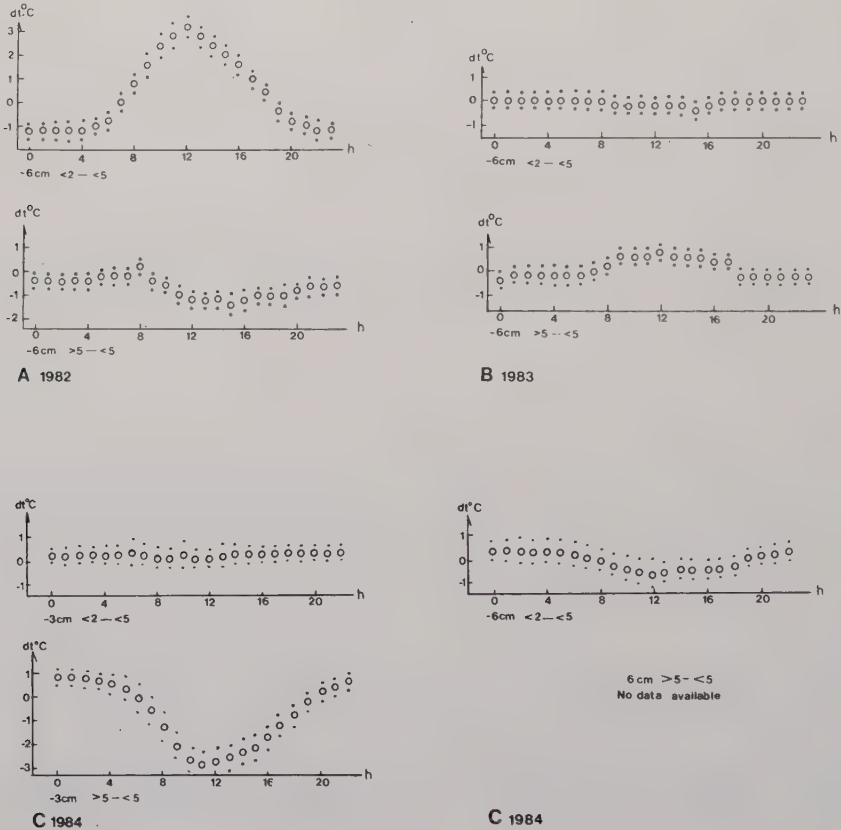


Figure 8.4. Mean hourly temperature anomalies of the soils <2 mm and >5 mm at the firm seedbottom, in relation to the soil <5 mm. The 95%-confidence limits are marked. Data from the periods 82.04.11-04.29 (A), 83.06.04-06.30 (B) and 84.05.09-06.30 (C).

was in general only smaller numerical differences. In nighttime the temperature was roughly the same for all the three plots, as well as at noon in the plot with the two finest structures. The most coarse plot, however, at noon at this level was 0.9°C warmer than the plot with medium fine aggregates.

In 1984 no differences were found between the two finer soils at the depth of 3 cm. However, at the depth 6 cm the medium fine soil shows a slightly greater amplitude than the finest soil. A big difference existed between the finer soils and the coarse; at noon the temperature was 2.5°C lower at the coarse soil, and at midnight 0.9°C higher. Temperature data are missing at the depth of 6 cm in the coarse soil, thus this anomaly can not be evaluated.

The analyses of the results from 1984 of the top layer measurements, only 1 cm below the surface, were omitted as a high standard deviation indicated an uncertainty of these measurements. Probably caused by a displacement of the sensors.

Finally, it is seen from figure 8.5 that the temperature amplitude of the aggregated soils in 1984 always was greater than this amplitude of the compact soil.

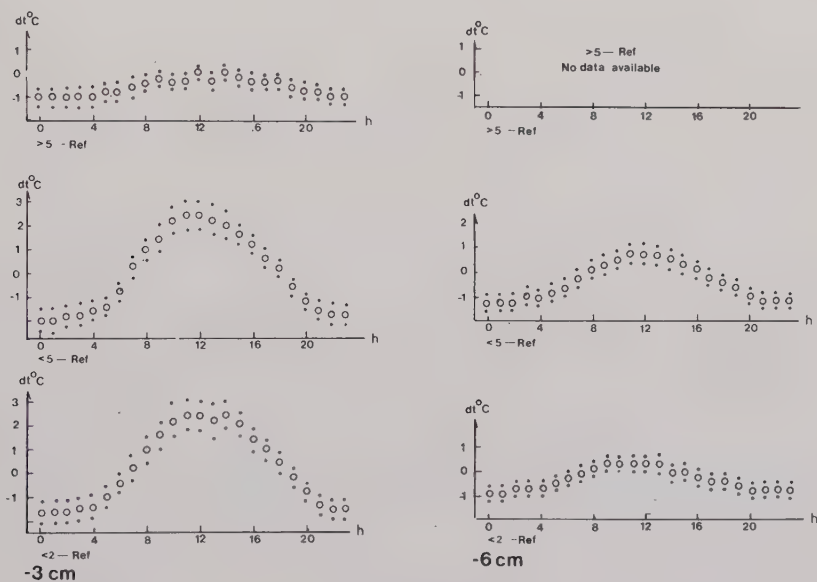


Figure 8.5. Mean hourly temperature anomalies on the firm seedbottom, of the soils <2 mm, <5 mm and >5 mm, in relation to a compact soil at the same depth. Also the 95%-confidence limits are marked. Data from the period 84.05.09-06.30.

Evaluation

The generally greater daily temperature in the finer soils may be explained by changes in thermal properties. If the differences were a result of different thermal conductivity, they must be caused by the fact that the finer soils have a greater conductivity than the coarser soils. One should here keep in mind that the soil structure below the examined aggregated structures are equivalent and compact. When energy is conducting through the soil, the highest resistance appears in the narrow interfaces between the aggregates. In soils with a fine aggregate structure, there are many "paths" the energy can flow when passing through the soil column; however in a vertical section these paths are frequently interrupted by interfaces, see figure 8.6. Thus the possible higher conductivity of the finer soils could be the result of the former effect dominating over the later. Also the deformation of the aggregates, caused by pressure, will affect the conductivity of the soil. However, no measurements which could verify this hypothesis were made on the heat conductivity.

Different thermal conductivities can not explain the lower amplitude of the untreated reference soil as this compact top soil must have a higher thermal conductivity than the more loosely aggregated soils: The lower amplitude of the reference plot can be a result of a difference in heat capacity. The compact untreated soil has the greatest density and because of this a high heat capacity which decreases the thermal effect of changes in energy. By Pappendick et al (1973) was shown a heat capacity in a compact untilled soil of $1.11 \text{ Jg}^{-1} \text{ } ^\circ\text{C}^{-1}$, and in the tilled topsoil of $0.70 \text{ Jg}^{-1} \text{ } ^\circ\text{C}^{-1}$. It is also likely that the raised daytime temperature of the aggregated soil, are caused by a reduced evaporation from these soils, in relation to the compact reference soil.

The lower mean temperature in the plot with aggregates $>5 \text{ mm}$, compared to the plot with aggregates $<5 \text{ mm}$, could be a result of the greater evaporation from the former plot. This greater evaporation from the coarse plot, is described in section 8.2.2.4 Evaporation. According to the following discussion on the results from measurements of soil moisture, this evaporation is concentrated to the upper layers.

The small differences in 1983 could be explained by the frequent rain this year, which very quickly ruined the original structures of the three beds.

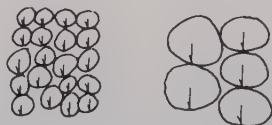


Figure 8.6. Sketch of the heat flux in two soils, having different aggregate sizes.

Table 8.2. Coefficients of correlation (r) with limits for 95% level of confidence, and of regression (k), recorded by linear regression between the temperature anomaly for different levels and times, and weather data.

		r	k
Noon, -3 cm			
Net radiation	>5 mm	0.15+/-0.41	$5.5 \cdot 10^{-4}$
	<5 mm	0.37+/-0.35	$3.4 \cdot 10^{-3}$
	<2 mm	0.55+/-0.29	$3.8 \cdot 10^{-3}$
Air temperature	>5 mm	0.04+/-0.31	$9.7 \cdot 10^{-3}$
	<5 mm	0.14+/-0.30	$8.5 \cdot 10^{-2}$
	<2 mm	0.34+/-0.28	$1.4 \cdot 10^{-1}$
Wind velocity	>5 mm	-0.34+/-0.28	$-1.1 \cdot 10^{-1}$
	<5 mm	-0.02+/-0.31	$-2.2 \cdot 10^{-2}$
	<2 mm	0.10+/-0.31	$1.9 \cdot 10^{-1}$
Noon, -6 cm			
Net radiation	>5 mm	Missing data	
	<5 mm	0.16+/-0.41	$1.5 \cdot 10^{-3}$
	<2 mm	0.07+/-0.42	$7.5 \cdot 10^{-2}$
Air temperature	>5 mm	Missing data	
	<5 mm	0.11+/-0.31	$8.5 \cdot 10^{-2}$
	<2 mm	0.16+/-0.30	$7.5 \cdot 10^{-2}$
Wind velocity	>5 mm	Missing data	
	<5 mm	0.17+/-0.30	$1.2 \cdot 10^{-1}$
	<2 mm	0.06+/-0.31	$1.1 \cdot 10^{-1}$
Midnight, -3 cm			
Net radiation	>5 mm	0.39+/-0.30	$5.5 \cdot 10^{-3}$
	<5 mm	0.53+/-0.25	$1.5 \cdot 10^{-2}$
	<2 mm	0.54+/-0.25	$1.3 \cdot 10^{-2}$
Air temperature	>5 mm	0.42+/-0.26	$5.5 \cdot 10^{-3}$
	<5 mm	0.70+/-0.16	$1.7 \cdot 10^{-1}$
	<2 mm	0.71+/-0.16	$1.6 \cdot 10^{-1}$
Wind velocity	>5 mm	0.42+/-0.27	$8.9 \cdot 10^{-2}$
	<5 mm	0.48+/-0.25	$2.3 \cdot 10^{-1}$
	<2 mm	0.43+/-0.27	$2.3 \cdot 10^{-1}$
Midnight, -6 cm			
Net radiation	>5 mm	Missing data	
	<5 mm	0.42+/-0.29	$7.1 \cdot 10^{-3}$
	<2 mm	0.35+/-0.31	$3.9 \cdot 10^{-2}$
Air temperature	>5 mm	Missing data	
	<5 mm	0.39+/-0.28	$4.1 \cdot 10^{-2}$
	<2 mm	0.21+/-0.31	$3.8 \cdot 10^{-2}$
Wind velocity	>5 mm	Missing data	
	<5 mm	0.21+/-0.31	$8.3 \cdot 10^{-2}$
	<2 mm	0.13+/-0.32	$7.4 \cdot 10^{-2}$

Table 8.3. Chi-two values of analyses between temperature anomaly and air humidity. The degree of freedom is 2. No correlations were significant.

	Noon	Midnight
>5 mm	3.71	0.08
<5 mm	0.01	0.70
<2 mm	0.43	0.14

The thermal result of a raised heat conductivity is opposite the effect of the raised heat capacity. The interference between these two factors could be the cause of the disturbance from the general relation, where the daily temperature amplitude was greatest at the finer soil.

8.2.2.2 Temperature, Influence of Weather

In this study, based only on data from 1984, analyses were made to find the influence of the general weather on the anomalies in temperature at noon and at midnight in the aggregated soils in relation to the dense reference soil. The relations between these

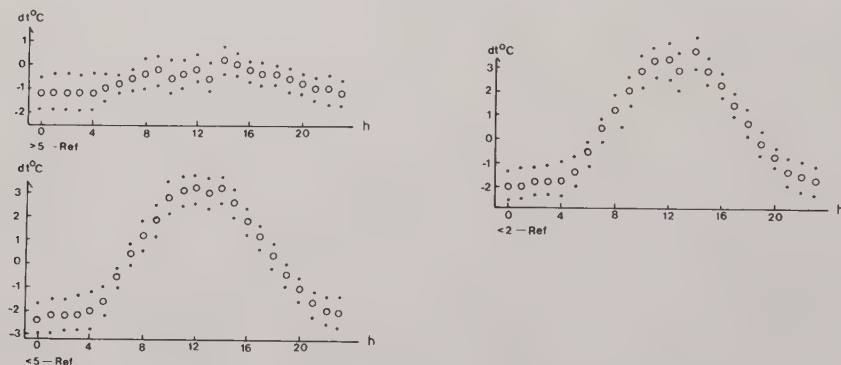


Figure 8.7. Mean hourly temperature anomalies in "cloud-less" conditions on the firm seedbottom, of the soils >5 mm, <5 mm and <2 mm, in relation to a compact soil at the same depth. Also the 95%-confidence limits are marked. Data from situations with an estimated cloud cover of $2/8$ or less, during the period 84.05.09-06.30.

anomalies and the climatic variables air temperature, net radiation and wind velocity were studied by means of regression analyses; and the influence of the two independent variables air humidity and soil moisture was tested by chi-two analyses.

An overview of the result is presented in tables 8.2-8.4. At the level -3 cm, the daytime positive anomaly of the aggregated soils increased with raised net radiation. For the two finer soils this correlation is significant at the 95%-level ($r=0.37$ and $r=0.55$ for the soils <5 mm and <2 mm, respectively). The correlation is not significant for the coarse soil ($r=0.15$).

At nighttime, a stronger outgoing radiation (i.e. lesser clouds) has increased the negative anomaly. This effect was particular great in the fine soils, but could also be noticed in the coarse soil ($r=0.39$, $r=0.53$ and $r=0.54$, for the plots with aggregates >5 mm, <5 mm and <2 mm, respectively).

Table 8.4. Chi-two values of analyses between temperature anomaly and soil moisture. The degree of freedom is 2. Only the correlation with <2 mm is significant at 95%.

	Noon	Midnight
>5 mm	1.31	0.56
<5 mm	1.13	0.70
<2 mm	8.47*	0.78

The mentioned correlations between net radiation and temperature anomalies indicate that a greater amplitude of the differences between the aggregated soil and the compact soil occurs in days with clear skies compare the figures 8.7 and 8.5. The result, with positive correlations between the anomaly and net radiation, is quite natural as the soil temperature ultimately is a function of the available amount of energy, the net radiation.

The same tendency, but without significant differences was found in correlations between the anomaly at noon and air temperature ($r=0.04$, $r=0.14$ and $r=0.36$, for the plots with aggregates >5 mm, <5 mm and <2 mm respectively). At midnight these correlations were significant though ($r=0.42$, $r=0.70$ and $r=0.71$, respectively).

Concerning the wind, a higher wind velocity during the day was correlated to a decreased anomaly in the surface-close layer of the coarse soil ($r=-0.34$). No similar effect were noticed for the finer soils ($r=-0.02$ and $r=0.10$ for the plots <5 mm and <2 mm respectively). An increase in wind velocity will increase the cooling by forced convection. This effect is most effective in the soil with the coarse structure, as the wind here not only can cool the surface layer, but also penetrate into the soil and cool the top volume of the soil. The more rough surface of the coarse soil will also increase the turbulence of the wind and thus further increase the cooling effect of the wind. This explains the negative correlation between anomaly and wind velocity for this coarse soil.

At the level 3 cm below the surface, an increased wind in the night has depressed the negative anomaly; the correlation between wind velocity and the anomaly is roughly the same for the three different aggregate structures ($r=0.42$, $r=0.48$ and $r=0.43$, for the three structures >5 mm, <5 mm and <2 mm, respectively). This could be a result of a covariation between wind and cloudiness, where an increased wind velocity was linked to a raised cloud cover and thus a reduced anomaly.

At the deeper level the correlation to weather factors was absent for the two finer soil structures. Because of missing data in this year no analyses have been made on correlations with the coarse soil at this deeper level.

Chi-two analyses between air humidity and anomalies, have neither for the situations at midnight, nor for the situations at noon, indicated any correlation between these variables, see table 8.3. However, an increase in soil moisture in daytime, according to a chi-two analysis, caused a decrease in the anomaly, may be a result of an increased evaporative cooling effect of the aggregated soil, see table 8.4.

8.2.2.3 Soil Moisture Content

When evaluating the results of soil moisture measurements, one should be aware of the fact that the gypsum blocks used are not very suitable for absolute measurements of this variable in a loose aggregated top soil, as the blocks are very big in relation to a single aggregate. Therefore the recorded data, must rather be considered as relative values of the moisture content. Some results of these measurements are presented in the figure 8.8.

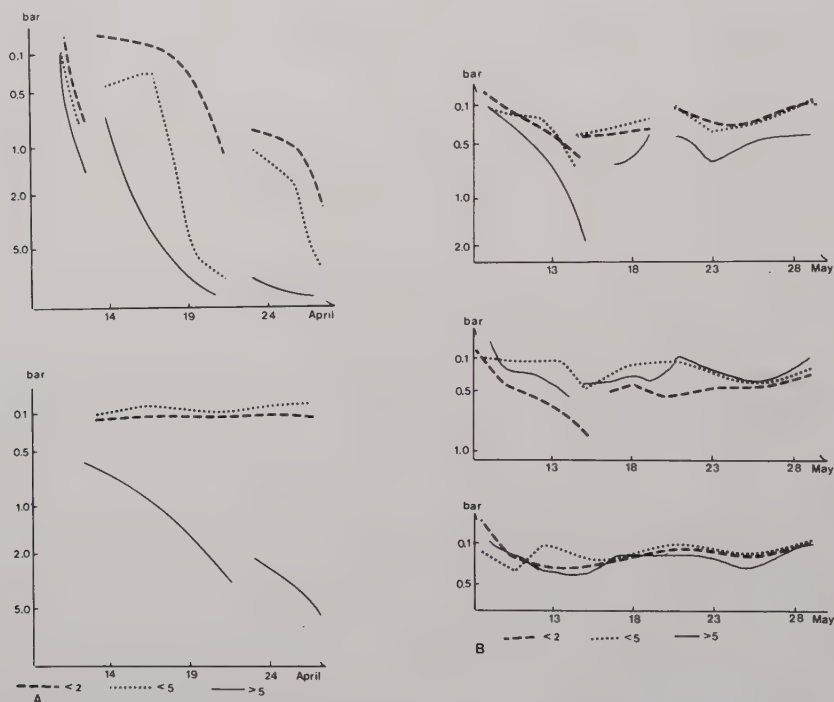


Figure 8.8. A) Soil water tension on the firm seedbottom at the depths of 3 cm (top) and 6 cm (bottom), for soils with different aggregate structures. Data from a period in April 1982. B) Soil water tension in soils of different aggregate structures: on the firm seedbottom at a depth of 3 cm (top; on the firm seedbottom at a depth of 6 cm (middle); and in the firm seedbottom at a depth of 6 cm (bottom).

At the most surface close layer, both years show a similar water sorption pattern, with the fastest rates of drying at the most coarse soil structure. On the seed bottom, at the deepest layer, the coarse soil also dried the fastest in 1982, but in 1984 the finest soil was the one that dried the fastest. The water content was measured as water tension and although the coarse soil according to this, in general seems to have dried the fastest, this soil does not need to have the lowest volumetric water content. Ameniya (1965) and Abrol & Palta (1970) have showed that the volumetric water content, at the same soil water tension, is higher for a coarse soil than for a soil with fine aggregates. According to Abrol & Palta, this is a result of reduced internal porosity of the aggregates by decreasing aggregate size, whereas larger aggregates have more blocked pores (causing an ink bottle effect) and dead end pores. Ameniya also showed that there is a very sharp difference between soils consisting of aggregates larger than 2 mm and of soils having aggregates smaller than 2 mm.

The results from 1984 indicate the following: In the coarse bed, it was possible for the wind to penetrate into the uppermost soil volume and there remove water from the aggregates; instead of that the water was transported upwards to the soil surface, either by capillary rising during the evaporation stage one, or by gas diffusion during the second stage of evaporation. The more turbulent wind flow over the rough coarse soil also increases the evaporative demand of the wind. This wind-influence thus accelerated the drying process in the upper layer. However, the influence did not reach down to the deepest layer, 6 cm below the surface, since no increase of water sorption was found here. At this layer, the dense soil will instead dry faster. Now because of a higher capillary conductivity for a soil consisting of finer aggregates (Ameniya, 1965), which makes it possible for the evaporation to proceed during a longer time, in the more effective evaporation stage one. These different evaporation stages are more carefully explained in chapter 4.

The fact that in the deepest level the coarse soil did dry the fastest in 1982, could be a result of stronger wind velocity this year; on average 4.8 m/s during the period 82.04.09-05.01, to compare with 4.1 m/s during the period 84.05.09-06.06. From this increased wind velocity, one can expect an increased depth at which the wind can influence the evaporation processes.

At the firm seed bottom, under a 6 cm thick layer of soil, the water retention was always very slow. According to Hide (1954), the evaporation through 5 cm or more of dry soil is very slow. In addition, the capillary contribution of water through the firm subsoil was probably sufficient to compensate these low evaporative losses of water.

8.2.2.4 Evaporation

The measurements of evaporation were made almost daily during the period 83.05.30-08.15.

A chi-two analysis on data from different periods of water sorption, with the rate of evaporation classed into three levels, has with a 95% significance, shown that the finest aggregates dried

the slowest, and the coarse soil dried the fastest in spite of the fact that the total envelope surface of the soil is greater in a finer soil. These results agree with the results of soil moisture measurements, mentioned above where a coarse soil dried quickly because of water transport by forced convection. One should here be aware of the fact that the drying process is the average of the whole soil volume, from the top layer down to the bottom of the pan at a depth of 5 cm.

8.2.2.5 Water Resorption in Soil Columns

Four columns, 30 cm deep and 10 cm wide, were filled with initially dry soil of different aggregate structures; <2 mm, <5 mm, 2-5 mm, and >5 mm. A fifth column was filled with compact soil. Measurements of water content were made with gypsum blocks on the bottom of each column.

To each column 10 mm of water was added. In the soils consisting of aggregates >5 mm and 2-5 mm, the front of the percolating water reached the bottom layer after 5 seconds and 15 seconds, respectively, see figure 8.9. Still after two hours, no such effect was noticed in the other soil columns. 24 hours after the water injection, the two coarse soil columns were still the wettest at the bottom, both with a water tension of 0.05 bars. The columns with the two finest aggregate structures, <5 mm and <2 mm, were also very wet, with a water tension of 0.06 bars. After 24 hours the soil with the compact structure, had the lowest content of soil moisture in the bottom, 0.21 bars.

This experiment shows the importance of having a coarse, loose and a well aggregated structure in the soil, when a good infiltration capacity is needed.

8.2.2.6 Water Sorption from Soil Columns

The soil columns described above were left indoors to dry after the initial water resorption; during this phase measurements on the soil moisture were made. The results of these measurements are presented in figure 8.10.

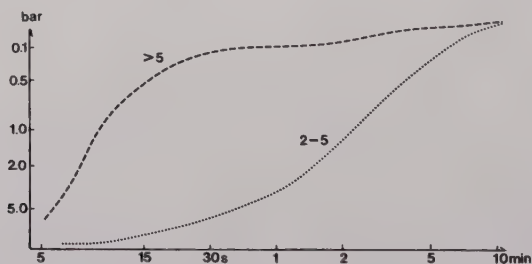


Figure 8.9. Water retention soil columns placed indoors with aggregates >5 mm, <5 mm at the depth of 30 cm, the first ten minutes after 10 mm water was added.

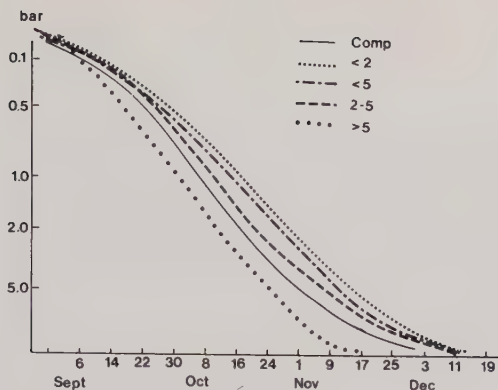


Figure 8.10. Water sorption at the bottom of 30 cm deep and 10 cm wide columns placed indoor, filled with soils of different structures.

From this figure is seen that the soil with the compact structure and the one with the very coarse structure dried at the fastest rate. In the coarse soil, the drying process could proceed quickly as the resistance to gas diffusion, which is the limiting process during the second stage of the evaporation, was very low. In the compact soil, the rapidly drying first stage of evaporation could proceed for a longer time because of high capillary conductivity, and thus cause a faster water sorption in the deeper layers.

When applying the result from this indoor experiment to field conditions, one must, however, be aware of the fact that the columns were not exposed to wind, which would have speeded up the drying process, especially for the coarse soils.

8.2.3 Conclusions

The experiments have shown that the aggregated soils developed a higher temperature during the day and a lower temperature during the night in the top soil layer, compared to the compact soil. These daytime anomalies have increased with decreased aggregate size.

If a low temperature in daytime is limiting the growth, a fine top soil should be the most suitable. If instead a low night temperature, maybe as frost, is limiting the growth, a dense untreated soil with a high heat capacity and/or strong heat conductivity, must be better.

In the surface close soil layer, -3 cm, the coarse soil dries the fastest. If water at this level and a low daytime temperature are limiting factors, a fine aggregated soil should be preferred.

8.3 THERMAL EFFECTS OF SOIL MOISTURE

8.3.1 Introduction

8.3.1.1 Background

The soil water is of agroclimatological interest, not only because of the effects on plant water relations or for transporting nutrients, but also as an agent intervening the temperature climate. The soil water modifies the thermal properties of the soil and also affects the evaporation and its cooling effects. Finally the water content at the soil surface will change the net radiation by changing the albedo of the soil surface (Barret & Curtis 1978).

The aim of this study was to see how the soil water modifies the surface close temperature in a soil.

8.3.1.2 Methods

Two different experiments were made. In one, temperatures at different levels were studied in three plots that were kept dry, periodically wetted, and continuously wetted, respectively. In this experiment also the thermal effect by the heat of the added water was studied. In the other experiment, the rise in temperature of initially frozen soil samples with different water contents was examined. Here was also seen the effect of soil water on the thawing process.

Field measurements of temperature in plots with different content of water, were made during the periods 82.07.12- 08.11 and 83.07.08-08.20. In each plot, 100*100 cm in size, temperatures were measured at three depths; in 1982 0.5, 3.0 and 6.0 cm and in 1983 at 1.0, 3.0 and 6.0 cm. In 1983 the most surface close measurements were deepened as the erosion very easily exposed the sensors at 0.5 cm depth. The measurements were made with thermocouples. In 1982 the heat flow through the layer 4.5 cm below the surface was measured. From these data the heat conductivity of the soils could be estimated.

Table 8.5. Amount of water, in mm, added artificially or by rain, to the different plots. A refers to the reference plot, B the periodically wetted and C the continuously wetted plot.

	1982	12/7	15/7	16/7	17/7	18/7	19/7	2/8	6/8
A									
B		6							
C		8	4	4		4	4	4	4
Rain					10.8				

	1983	8/7	11/7	13/7	15/7	17/7	18/7	20/7	22/7	10/8	12/8
A											
B					4				4		
C		4	4	4	12		4	4	4	4	4
Rain				1.0		2.8					

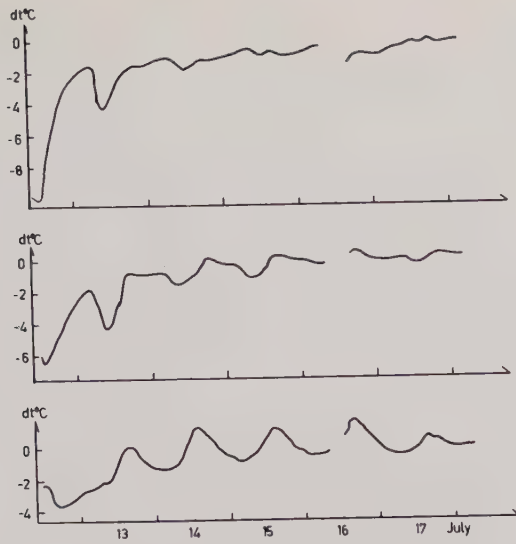


Figure 8.11. Temperature anomalies at the depths 0.5 cm, 3 cm and 6 cm, of an initially wetted plot, in relation to the corresponding level under a non-irrigated plot. Data from July 1982.

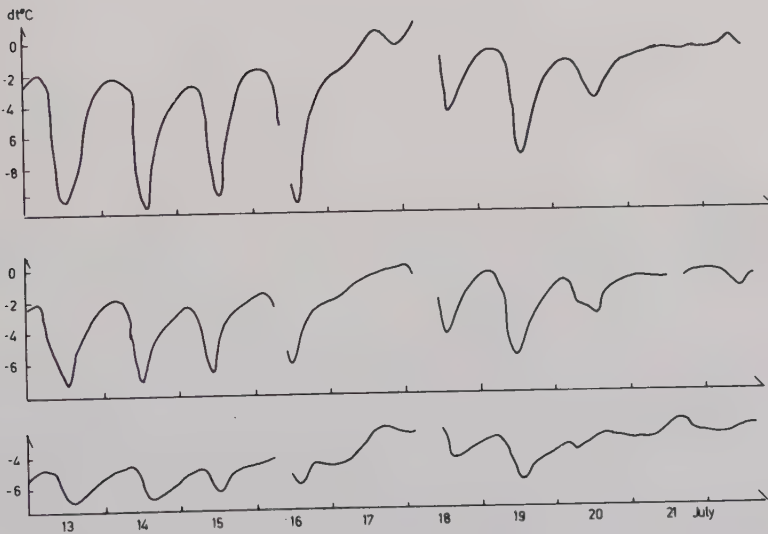


Figure 8.12. Temperature anomalies at the depths 0.5 cm, 3 cm and 6 cm, of a continuously wetted plot, in relation to the corresponding level under a non-irrigated plot. Data from July 1982.

In table 8.5 is shown how much water that was added to each plot, both artificially and by precipitation.

In the study concerned with the temperature rise of initially frozen soils, soil samples with three different contents of water (low, about 5% by weight; medium, about 12%; and high, about 20%) were examined.

The samples, placed in closed plastic boxes 8 cm in square, were frozen to -20°C . After this the samples were moved into a room with an ambient air temperature of $+22^{\circ}\text{C}$. The rise of temperature in the middle of the samples was followed by measurements with thermocouples every fifth minute. This trial was repeated in four series.

As the transport of the samples from the freezer to the acquisition system took some time, the rise in temperature was followed first from a soil temperature of some five degrees below zero.

8.3.2 Results and Evaluation

8.3.2.1 Temperature, Field Experiments

For both years it is quite evident though that an additional amount of water has decreased the daily amplitude of the temperature. The water has also decreased the daily mean temperature. This is seen from figure 8.11 and 8.12 where an example of the anomalies of the continuously wetted plot and the more sporadically wetted plot, both in relation to the "dry plot", are presented. Notice how the temperature anomaly is decreasing by a reduced content of water, as the soil where water only was added initially dries. In July 17, 1982, the smooth sinuous change of the daily anomaly of the continuously wetted plot was interrupted and the anomaly was decreased remarkably. This was a result of precipitation; 10.9 mm of water fell this day, which moistened also the reference plot.

The decrease in daily mean temperature was quite certainly an effect of the evaporative cooling. This phenomenon could also explain the decreased daily amplitude of the wetted soils, as the evaporative cooling was most effective in daytime.

The heat conductivity at -4.5 cm was determined on the basis of the hourly vertical temperature gradient in the soil and contemporary heat flux during the period 82.07.13-07.20 (the data from sunrise and sunset excluded). For the dry soil the heat conductivity (with 95% confidence limit) was estimated to $0.36 \pm 0.09 \text{ W/m}^{\circ}\text{C}$; for the soil wetted only sporadically $0.84 \pm 0.10 \text{ W/m}^{\circ}\text{C}$; and for the continuously water soil to $0.91 \pm 0.16 \text{ W/m}^{\circ}\text{C}$. This rise in conductivity through increased soil moisture could be compared with the figures mentioned by van Wijk and de Vries (1963), where the heat conductivity of a completely dry soil was $0.25 \text{ W/m}^{\circ}\text{C}$, for soils with a water content by volume of 20% and 40% the conductivity was $1.18 \text{ W/m}^{\circ}\text{C}$ and $1.58 \text{ W/m}^{\circ}\text{C}$ respectively. Also Nakshabandi and Kohnke (1965) mentions similar figures: $0.31 \text{ W/m}^{\circ}\text{C}$ for a silty loam with a soil moisture content of 5% (by weight), $0.54 \text{ W/m}^{\circ}\text{C}$ at 10% and $1.25 \text{ W/m}^{\circ}\text{C}$ at 20%. Nakshabandi and Kohnke also showed that the conductivity at the same moisture

content by weight, was decreased by a finer texture of the soil; however, the texture did not affect the conductivity if the soil moisture tension was held at a constant level.

The raised heat conductivity causes in daytime more heat to flow to deeper, and cooler, layers. Because of this the temperature at the most surface close layers is further decreased. At nighttime, the higher conductivity will increase the compensation of the radiative cooling at the surface through a more intense heat flux from the deeper, and now warmer, layers. The result is now a relatively increased temperature in the surface layers. The higher thermal conductivity will thus reduce the daily amplitude of these layers.

At deeper layers this increased heat flow and increased exchange of energy will instead tend to increase the temperature amplitude. This could also be noticed in figure 8.11 at the deepest layers, -6 cm. After the first initially intense cooling when the soil still was very moist and the evaporation rapid, the temperature amplitude at this level was higher in the moist soils than in the dry soils.

Furthermore, the increased content of water also increases the heat capacity of the soil. This decreases the thermal effects of changes in energy content, and thus also decreases the daily amplitude of temperature.

The increased emissivity and decreased albedo of a moist soil have an effect on the temperature, which is opposite to the increased heat conductivity. In daytime, the moist and darker soil will absorb more incoming radiation and at nighttime, the increased emissivity will increase the radiative losses. These effects tend to increase the amplitude of temperature at the surface. However, compared to the changes of conductivity and evaporative cooling, these effects are small and have therefore been disregarded in this study.

On August 28, 1983, one liter 33°C hot water was evenly poured over a plot, 40*40 cm in size, in order to study how the hot water affected the soil temperatures at the depths of 3, 6 and 10 cm. From figure 8.13 is seen that the soil initially was warmed by the hot water. This effect was strongest at the top layers. The positive anomaly did, though, decline very rapidly and at -3 cm it had diminished within 30 minutes, at -5 cm after one hour and at -10 cm after two hours. After this initial period, the temperatures at -3 cm and -5 cm were lower in daytime under the moist surfaces than in the dry ground, just like the result from the other studies. Also from this study could be seen that the daily amplitude at the deep layer, -10 cm, after the initial period of intense evaporative cooling, was higher than the amplitude of the dry surface.

A similar study was made with water much cooler than the soil, see figure 8.14. Also this study showed that the soil temperature after an initial negative anomaly just after the water injection, rapidly increase to a level slightly lower than in the dry soil.

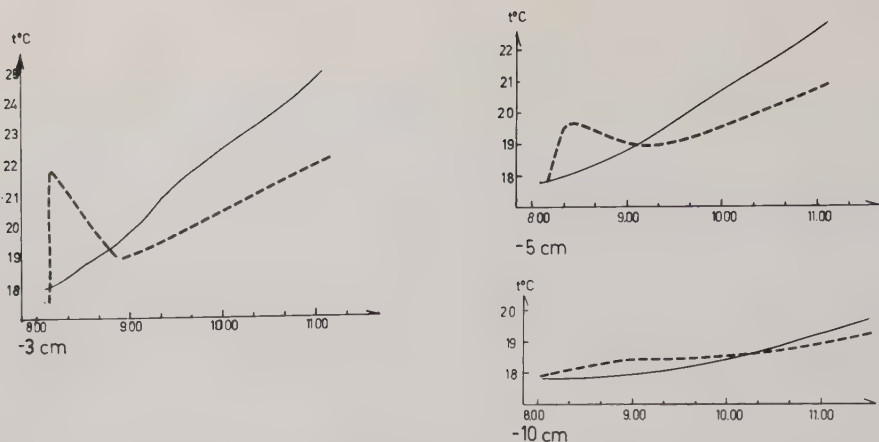


Figure 8.13. Temperatures at different depths under a surface initially watered with 6 mm of 33° hot water, and under a non-irrigated plot. The study was done on August 28, 1983.

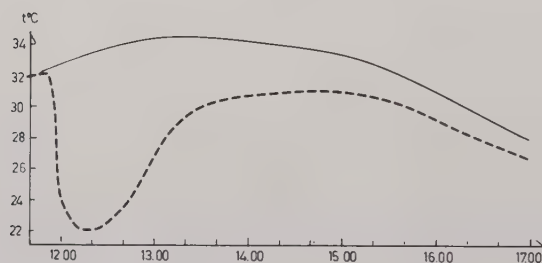


Figure 8.14. Soil temperatures 0.5 cm under a surface initially watered with 2 mm of 21°C cold water, and under a non-irrigated plot. The study was done on May 22, 1981.

8.3.2.2 Thermal Diffusion

In the study of the initially frozen soil samples, the temperature rose quite rapidly from -20°C to the freezing point. However, the most remarkable effect in this study was the thawing processes which delayed the temperature increase at 0°C, see figure 8.15.

At the driest soil this delay was estimated to only five minutes; at the medium moist sample to some half hour; and at the very moist soil to more than an hour. This trial was repeated four times and the average estimated delays of the three moisture levels were 6 minutes, 27 minutes and 72 minutes, respectively.

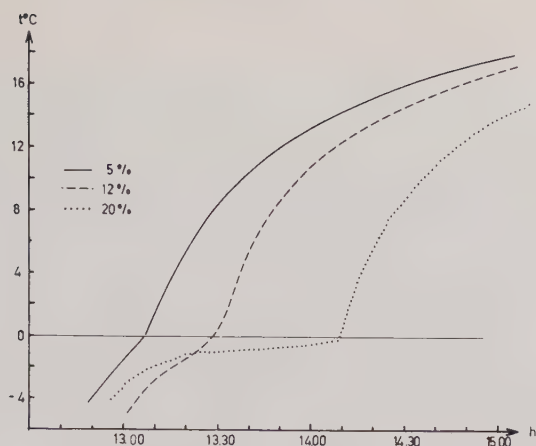


Figure 8.15. The progress of temperature rise in initially frozen soil samples of different soil water contents (5%, 12% and 20%, respectively). Confer with the text for further information.

It should here be mentioned the remarked higher heat conductivity of ice in relation to water; $2.16 \text{ W/m}^{\circ}\text{C}$ versus $0.57 \text{ W/m}^{\circ}\text{C}$. Of interest is also that the heat capacity of ice is roughly the half of the heat capacity of water; $1.88 \text{ J/g}^{\circ}\text{C}$ versus $4.18 \text{ J/g}^{\circ}\text{C}$ (de Vries 1963). These two circumstances, together with the higher thermal gradient when the soil sample still is cold, explains the very fast temperature rise from -20°C to the freezing point.

The time needed for the temperature in the middle of the sample to rise from 5°C to 15°C was examined in a separate study. In general this time was longer for the moist samples than for the dry samples. The medium moist samples needed 5% and the very moist samples needed 9% more time than the dry samples. However, the recorded differences are not significant.

At this study the effects of evaporative cooling were diminished as the boxes were completely closed, and the factors of importance were the effects of increased heat capacity and increased heat conductivity, both caused by the increased soil moisture. These two effects on the temperature climate in the middle of the soil samples are contradictory to each other. The increased heat conductivity will rise the energy transport to the middle of the sample. On the other hand the increased heat capacity will lower the thermal effects of the changes of energy in the middle of the sample. Thus will the two processes tend to cancel each other, which could explain why no significant effects of the thermal diffusivity (the rate of heat conductivity and heat capacity) or differences in rise of temperature were noticed. According to Rider (1957) a rise in soil moisture when the soil is rather dry, will increase the thermal diffusivity and the rise of temperature. At higher moisture contents this effect will be reversed with a decreased thermal diffusivity.

8.3.3 Conclusions

The water in the soil acts on the temperature in different ways, and the final result is depending both on the content of soil moisture and the level under the ground surface. One of the main effects is the evaporative cooling, which of course is most intense at the surface. However, if the soil was moist, the evaporative cooling was found still quite important at 10 cm below the surface. How strong this cooling will be, depends on factors as soil moisture, water conductivity to support the soil moisture at the surface, and the evaporative demand: wind velocity, relative humidity, air temperature etc. In one trial the temperature anomaly at -0.5 cm was 15°C and at -6 cm 4°C. As the evaporation is highest at daytime, this evaporative cooling will besides reducing the daily mean temperature, also decrease the daily amplitude.

Kohl (1973) showed in a study an average temperature depression of 4°C at the 10 cm depth in a soil that was irrigated daily. He also showed that this cooling effect was higher for a bare soil than for a soil covered by crop. When the irrigation stopped, the thermal effects declined within a week. His results do well correspond to the results in this study.

A practical use of this evaporative cooling is shown by Erez & Couvillon (1983), where the bud temperature was lowered by irrigation, in order to delay the blooming until the frost risk was reduced.

Another important effect of the soil water on temperature is caused by the changes of heat diffusivity. The increased heat capacity will at all levels decrease the daily temperature amplitude. On the other hand the effects of changed heat conductivity differ at different levels. At the surface, the rise of heat conductivity decreases the daily amplitude: in daytime the energy losses to deeper levels will increase, and at nighttime the higher heat conductivity will increase the compensation of radiative losses by an increased heat flux from below. At deeper layers the raised heat conductivity increases the daytime energy input, but also increases the energy losses at nighttime. This will instead tend to increase the amplitude, though the effect will be repressed by the rise of heat capacity. These effects with a lower amplitude at the surface and a greater amplitude in the deeper layers were also noticed in the experiments.

From the results could be seen that a frequent irrigation, which keeps the soil moist, reduces the daytime soil temperature, even at 10 cm below the surface. This is mainly due to an increase of evaporation, but at the surface it is also a result of changes in heat conductivity. At a less frequent irrigation, this evaporation will not be so intense and thus will the daytime temperature depletion diminish. At deeper layers the daytime temperature might then even rise as a result of higher heat conductivity which then is not interferred by an high evaporative cooling.

The process of thawing is also important to notice, where a moist soil needs more time to thaw than a dry soil. On the contrary, if one ignore the influence of evaporative cooling, a moist soil will not freeze below zero as fast as a drier soil. This is of course of interest for the development of nighttime temperatures, and frost situations.

8.4 EFFECTS OF COMPACTION

8.4.1 Introduction

8.4.1.1 Background

Earlier studies on emergence and root growth have shown that a light compaction often improves the crop production (Eriksson et al 1974 and Fergedal 1971). One reason for this is improved soil moisture conditions. For instance a light compaction will increase the water content by volume. A light compaction could also convert bigger pores to smaller pores which better can hold water, thus the field capacity of the soil will increase (Heinonen 1964). Furtheron, the compaction also affects the capillary conductivity, which acts on the support of water to the more surface-close layers and on the evaporation. On the other hand a compaction of the bigger pores decreases the infiltration capacity and thus increases the risk for erosion by run off. This, as well as other factors (increased resistance to penetration, decreased gas diffusion), could instead decrease the production of compacted soils (Trowse 1971).

8.4.1.2 The Plots

In order to describe the thermal effects of soil compaction, the daily temperature cycles were examined in soils with three different degrees of compaction. In another experiment, the rise in temperature of initially frozen soil samples with different degrees of compaction, when exposed to indoor temperatures, was studied. Finally, a study dealt with evaluating the effects on evaporation and changes in soil moisture, caused by the compaction. These experiments were generally made in 1983.

8.4.1.3 Methods

In all the experiments, the compactations were made manually. When studying the daily temperature cycle, plots 50*50 cm in size, with three different levels of compaction were examined. In each plot the temperature was measured at the depths 3 cm, 6 cm and 9 cm. These measurements were made during the period 83.07.11-08.30. Bulk densities (dry) of the soils from the three plots were 1.13, 1.37 and 1.50 kg/dm³, respectively. In this experiment also the soil moisture content at -5 cm was measured by using gypsum blocks.

In the experiment dealing with the thawing of initially frozen soil samples, the samples placed in plastic boxes 8 cm in square, were frozen to -20°C. These samples were then placed indoors and exposed to an ambient air temperature of 22°C. In this experiment the temperature in the middle of the sample was measured with a thermocouple every fifth minute. The trial was repeated in four series, each with three levels of compaction. The bulk densities (dry) of the different soil samples are presented in table 8.6.

When estimating the effects on evaporation, six aluminium pans placed outdoors and filled with soils of three different levels of compaction were weighed every day. On the basis of the changes in weight the daily evaporation from the different pans was calculated.

8.4.2 Results and Evaluation
8.4.2.1 In Situ Measurements

Because of technical problems with the acquisition system, only three shorter periods were examined: July 11-15, July 27-30 and August 15-20. Furthermore, as the data initially had to be sorted manually, only temperature data from every other hour were used.

The measured anomalies of temperatures at the lightly and heavily compacted soils in relation to the soil which was not compacted, are presented in figure 8.16. From this figure is seen that the greatest daily amplitude at the most surface close level occurs in the loose soil and that there were no greater differences between the two more compacted soils. At -6 cm and -9 cm, on the contrary, the most compacted soil shows the greatest daily amplitude.

Table 8.6. Bulk density (kg/dm³) of the different samples in three in vitro studies.

Trial	No comp.	Light comp.	Heavy comp.
1	1.05	1.12	1.26
2	1.04	1.13	1.21
3	1.02	1.15	1.24
4	1.05	1.14	1.26

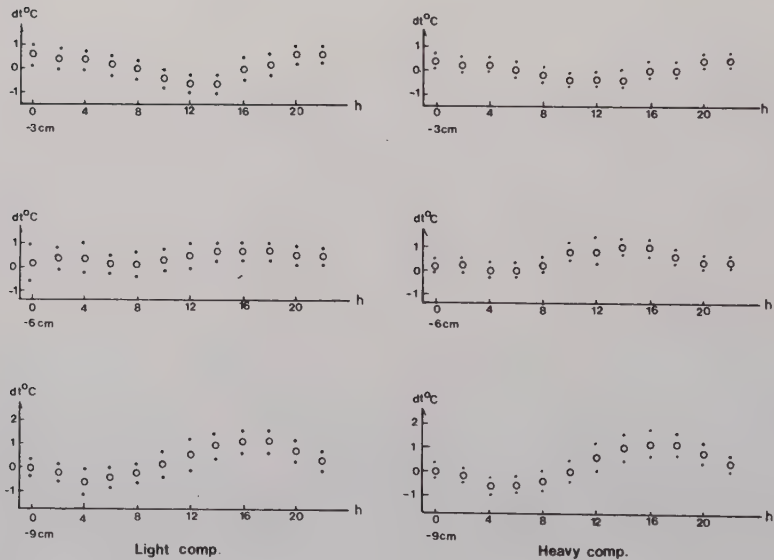


Figure 8.16. Mean hourly temperature anomalies of the lightly and heavily compacted soils in relation to a non-compacted soil at the same depth. The 95%-confidence limits are marked. Data from the period 83.07.11-08.15.

The lower amplitudes at the surface close layers for the compacted soils were probably a result of the greater thermal conductivity of these soils (see de Vries 1963 and Willis & Ranay 1971). Due to this higher thermal conductivity, energy was more efficiently conducted from the surface down to deeper layers and thus the daytime warming of the top layers was decreased. At nighttime when the surface is cooled by radiation, the higher conductivity will result in an increase flow of energy from deeper layers to the surface, and thus compensate against this cooling.

Furthermore, the increased bulk density, increases the heat capacity, which also decreases the thermal effects on heat flow, and thus decreases the daily amplitude (de Vries 1963).

At the deeper layers, -6 and -9 cm, the increased thermal conductivity of the denser soils, which increased the flow of energy, instead raised the amplitude of temperature. The greater heat capacity in the denser soils tended to repress this effect of raised amplitude, but evidently not so much that the amplitude is decreased.

8.4.2.2 Temperature Rise of Frozen Soil Samples

In figure 8.17 is presented the temperature rise in one trial with the initially frozen soil samples. Despite the fact that the compacted soils have a higher heat conductivity the compacted soils in these experiments warmed up at the slowest rate. A t-test showed a significant longer time for rising the temperature from 10°C to 21°C, at the most compacted soils, compared with the soil which was not compacted. As the heat capacity, too, is increased by compaction, the lower thermal diffusivity (the rate of heat conductivity and heat capacity) of the compacted soils must here be a result of a greater increase of heat capacity in relation to the increase of heat conductivity. According to Edling & Fergedal (1972), however, it is more common to find a higher thermal diffusivity with increased compaction.

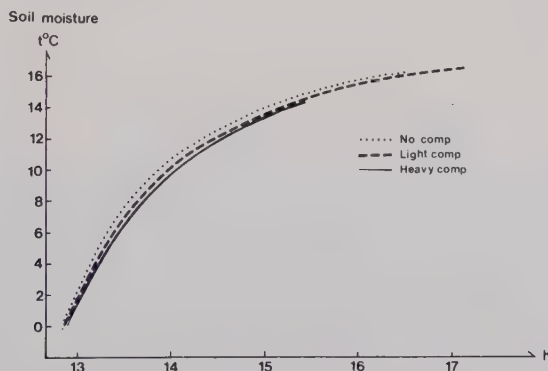


Figure 8.17. The progress of temperature rise in initially frozen soil samples of different levels of compaction (1.04 kg/dm^3 , 1.14 kg/dm^3 and 1.24 kg/dm^3), respectively). Confer the text for further information.

8.4.2.3 Evaporation and Soil Moisture

Estimations of evaporation from the soil samples in aluminium pans, were made during the period 83.07.05-08.15. From this study was found that the sample with the most compacted soil initially showed the highest rate of evaporation, see figure 8.18 A. This could be a result of higher capillary conductivity, which in turn will maintain the evaporation at the faster stage one for a longer period. Measurements of the moisture at the in situ soils, showed that the loosest soils had dried at the fastest rate, see figure 8.18 B. Also this could be explained by the raised capillary conductivity of the compacted soils, which in spite of a high rate of evaporation could maintain a higher content of soil moisture in the surface-close layers by an efficient capillary input of water from deeper layers. This means that a compact soil, in spite of the greater evaporation, will not dry up as fast in the top layers as a looser soil; on the contrary, it will dry faster at deeper layers. The slower rate of water sorption at the surface of the compacted in situ soils may also be a result of an increased field capacity, when macro pores, which cannot hold water, have converted to finer pores which better can hold water. This situation means that after the spontaneous drainage after rain, lightly compacted soil has more water than a looser soil. However, a rainfall might ruin the soil structure and cause negative effects by erosion and clodding the pores. Thus will the positive effects of a an increased field capacity be reduced. One should also notice that the compaction decreases the infiltration of free water into the soil, and thus decreases water recharge at rain. Which factor that will dominate, depends on soil structure, degree of compaction and characteristics of the rain.

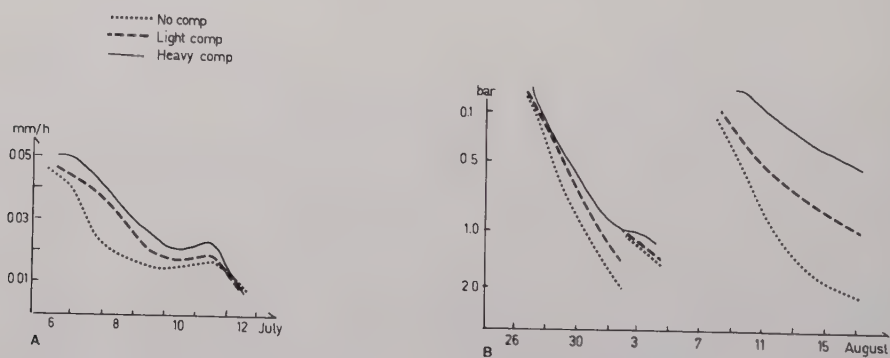


Figure 8.18. A) The rate of evaporation from soil samples of different degrees of compaction during a period of sorption in July 1983. B) Soil moisture tension at -5 cm of in situ soils with different degrees of compaction during a period in July-August 1983.

8.4.3 Conclusions

The compaction decreased the daily amplitude of temperature in the most surface close layers. According to this, the risk of nighttime frost damage is greatest in a loose soil. On the other hand this loose soil will in the surface layers get a higher temperature in daytime, but in deeper layers a higher temperature at nighttime.

The compaction also improved the soil moisture at the surface layers, probably partly because of higher capillary conductivity, and partly because of an increased volumetric field capacity. To the contrary one might expect a higher rate of water sorption at the deeper layers of a more compacted soil, as the evaporation may proceed in the fast stage one for a longer period.

These factors indicate that a more compact soil structure will improve the climatic environment for the emerging plants. However, one should consider that with compactions follow other problems as increased resistance against root penetration and a decreased exchange of oxygen, which may be dangerous to the young plant. Furthermore, an increased compaction may also decrease the infiltration capacity, which in turn could raise the surface run off and cause soil destruction by erosion. Nevertheless, compaction could be seen as one possible way to modify the climate for the emerging plants within some limits.

8.5 EFFECTS OF STONE CONTENT

8.5.1 Introduction

8.5.1.1 Background

The stone content of a soil might affect the temperature climate by a change of the soil's thermal properties. Besides this, the stones will influence water movement, and if present in the surface, tend to repress evaporation. This last effect was used in ancient vineyards and orchards in China and in the Mediterranean countries in order to save water. This technique also prevented damage by erosion (Heinonen 1985, p 88).

8.5.1.2 The Plots

The purpose of these studies was to evaluate the effects of stones on soil temperature and soil moisture. Apart from the studies dealing with evaporation which were made in 1983, the field work was carried out in 1984. Four soil profiles were constructed, with different contents of stones (each stone was 5-10 cm in size). The plots were 50*50 cm wide and 20 cm deep. In one profile 21 kg of stones, 5-10 cm in diameter, were evenly distributed; in one profile 10 kg of stones were evenly distributed; and in one plot 18 kg of stones were concentrated to the lower 10 cm of the profile. Finally, in one reference plot no stones were added. See also table 8.7.

The measurements of soil temperature and soil moisture were made during the period 84.06.21-07.22. During the first and the last thirds of this period, the weather was mainly cloudy with shorter spells of rain. The middle period was bright and with only weaker winds.

During the period 1983.06.07-08.05 the daily evaporation from six soil samples (two with no stones and four with different stone cover), placed in aluminium pans, was calculated. The percental stone coverages were 17%, 20%, 27% and 33%, respectively.

8.5.1.3 Methods

The temperature was measured with thermocouples at two levels in each plot: -5 cm and -10 cm. The soil moisture was measured with gypsum blocks at the depth 10 cm. In the experiment dealing with the rates of evaporation the samples were weighed daily.

8.5.2 Results and Evaluation

8.5.2.1 Soil Temperature

Recorded anomalies of soil temperature, in relation to the situation of the stone free soil, are presented in figure 8.19. From these graphs is seen that there is no change in daily mean temperature. In relation to the stone free profile, the daily amplitude at 5 cm below the surface was lower in the plot with stones only at the deeper layer, the "subsoil". In the plot with a high content of stones through the whole profile, this daily amplitude was only somewhat lower. Finally at the profile with a low stone content no thermal effects were significant, even if a tendency to a lower amplitude could be noticed.

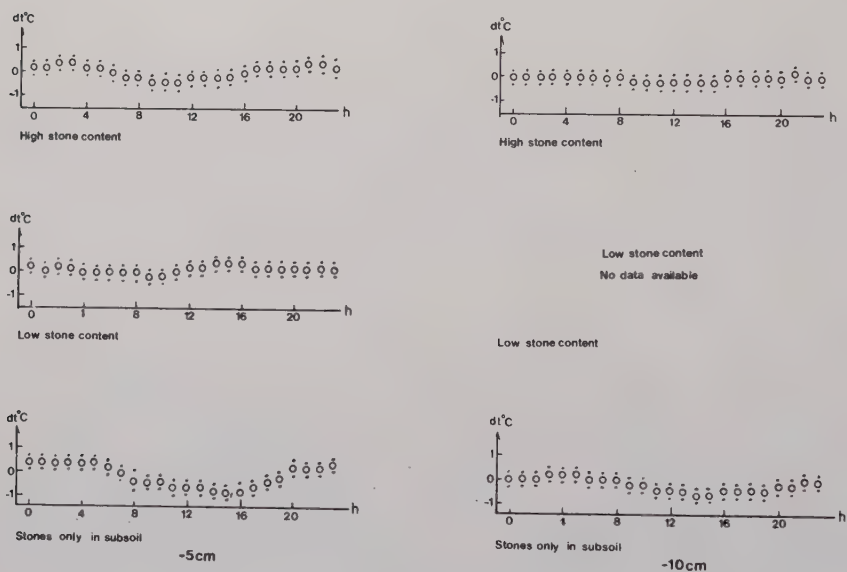


Figure 8.19. Mean hourly temperature anomalies of soils with a high stone content, low stone content and stones only in the subsoil, in relation to a stone-free soil at the same depth. The 95%-confidence limits are marked. Data from the period 84.06.12-08.23.

Table 8.7. The volumetric stone content in the different profiles, based on a bulk density for the stones of 2.6 kg/dm^3 (van Wijk & de Vries 1963).

Plot	%
Reference	0
High stone content	16
Low stone content	8
Stones at the base	14

At the deeper level, 10 cm below the surface, sufficient data was not achieved from the plot with a relative low content of stones. At the plot with stones only in the subsoil, the same tendency as at the surface-close layer could be noticed, with a lower daily amplitude. At the plot with a great stone content, the daily temperature development was equal to the situation at the reference plot.

The lower daily amplitude of temperature in the plots with stones could be seen as a result of the greater heat conductivity of stones, in relation to the pure soil column. According to van Wijk & de Vries (1963) the heat conductivity in stones (quartz) is about seven to eight times greater than in a clayey soil with a water content of 20% (by volume). This means that a subsurface layer in a stony profile in daytime will receive more energy from above, but also loose more energy to deeper layers. At nighttime the layer will receive more energy from deeper layers, but conduct more to shallow layers. This in turn will cause a increased temperature amplitude at deeper layers and the observed decrease at more surface close layers.

At the plot with stones only in the subsoil, the surface-close layers received in daytime the same amount of energy as a layer at the same depth of the stone-free profile. However, the losses of energy to deeper layers has increased, due to the greater conductivity of the subsoil. The results of this in daytime will be a decreased temperature at the surface layer of this profile. At nighttime the situation is the opposite: the surface close layer of the profile, with stones only in the subsoil, will loose almost the same amount of energy upwards as the stone-free profile, but will gain more energy from below. At nighttime the temperature of the profile with stones in the subsoil will therefore not be so low as the profile of the stone-free soil.

As the heat capacity of soils and stones is quite similar, especially in deeper layers where the soil is compact, this variable hardly affected the temperature in the stony plots.

One should notice that the stone content in the stony plots was extreme. It is therefore hardly possible to directly apply these results in order to modify the temperature in the agricultural soil of this part in Sweden.

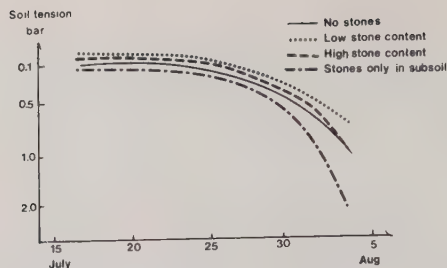


Figure 8.20. Soil moisture tension at the depth of 10 cm, during a period of sorption in July 1984, in plots with different stone content.

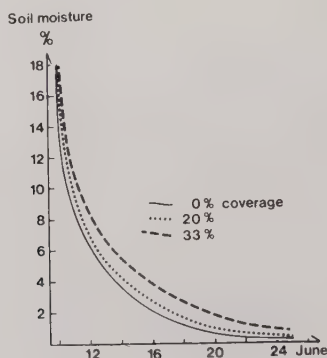


Figure 8.21. Soil moisture content in aluminium pans filled with soils with a different stone coverage, during a period of sorption in June 1983.

8.5.2.2 Soil Moisture

As mentioned before, the weather was mainly clouded and rain fell frequently during the studied period. However, in late June there was a period of clear and dry weather, when the soils dried up. The results of measurements of soil moisture during this period at 10 cm below the surface are presented in figure 8.20.

From this figure is seen that the water retention was hardly affected by the stones that were evenly distributed in the profile. However, the upper layer of the soil profile with a high content of stones in the subsoil, did dry much faster than the other profiles. This was probably not a result of higher evaporation at this profile, but a lower hydraulic conductivity in the subsoil. This decreases the water movement from below to the more surface-close layers, a process which to some extent compensates the surface close evaporative losses. Of course the stones in the other plots also have obstructed the water movement, but at these profiles, due to the stones in the top layer, this water movement has to support a smaller volume of soil.

As the soil moisture tension in the pure soil part of the stony profiles were equal to the tension at the profiles free from stones, the total water content at the stony profiles was lower than the water content at the reference soil without an stones.

8.5.2.3 Evaporation

In figure 8.21 is presented the moisture content, percent by weight, under a period of sorption in the soil samples covered by different amounts of stones. From the figure is seen that the evaporation is repressed by an increased cover of stones. Especially in the beginning of the sorption, during the evaporation stage one, the stones had a great influence on the evaporation. The delay in time of this drying process was greatest in the midtime of the sorption at a soil moisture content of 2-4%. From the figure 8.21 is seen that the soil with a stone cover of 33% reaches this level of dryness three to four days later than the soil with no covering stone layer. This is a pronounced delay as the unprotected soil reached this level of dryness only a week after it was thoroughly moistened. Also in this study one should be aware of the fact that these stone covers have been extraordinary. Similar results could however be received by a coverage of gravel. Such treatment may also further improve the soil moisture conditions, as the infiltration capacity is rised.

8.5.3 Conclusions

The studies on the influence of stones on soil temperature showed a reduced daily temperature amplitude at the surface of a stony soil profile. The reduction was probably caused by an increased heat conductivity. The stones have also affected the soil moisture content and evaporation by reducing the hydraulic conductivity and, when presented at the surface, reducing the evaporation.

One must, though, have a great amount of stones in order to receive a significant effect. Therefore it is doubtful if in an ordinary cultivation system in the southern part of Sweden can use this technique for modifying the crop climate.

8.6 EFFECTS OF HARROWING

8.6.1 Introduction

8.6.1.1 Background

Through harrowing, soil particles break up into finer aggregates. Studies by others have been made on how this treatment acts on the yield (Nilsson, 1977 and Cederlund 1982). However, the treatment primarily affects the characteristics of the soil, both thermal and hydrological, and thus secondarily, affects the crop growth through a changed microclimate.

The aim of this study was to evaluate how different intensities of harrowing can affect the climatic variables, soil temperature and soil moisture. These variables, as well as heat flow, evaporation, and different variables describing soil structure, therefore were measured at different levels in plots which was harrowed once, three times and six times, respectively.

8.6.1.2 The Methods

In the years 1982 and 1983, the temperature was measured at three levels, -3 cm, -6 cm and -10 cm, in plots that were harrowed once, three times and six times, respectively. In 1982, the heat flow at the three plots, through a cross section of the soil at the depth 4.5 cm, also was measured. Based on data from these measurements the heat conductivity of the soils was estimated. This year the soil moisture was measured with gypsum blocks at the depth of 4.5, 6 and 9 cm. In 1983 the soil moisture and a relative value of the actual evaporation were determined by daily weighing of pans filled with soil from the different plots.

8.6.1.3 The Plots

In the two years, the three intensities of harrowing were repeated with three different depths, 1.5 cm, 3 cm and 6 cm, according to the control of the harrow. However, evaluation of climatic effects was only made at the plot harrowed to a depth of 6 cm. In 1983, in order to improve the results of the study on the emergence, all nine combinations were repeated twice. Each plot was only 11.4*2.9 m in size, which is far too small for receiving an ordinary effect of the harrowing; the speed of the vehicle will be too low.

The measurements of the climatic variables were done mainly during the periods 1982.04.27-07.07 and 1983.06.04-07.03. For a description of the weather during these periods, see chapter 1. It could however be stated here that the soil was very wet at the time of tilling in 1983. This has decreased the effect of this treatment. Also June this year was extraordinary wet, in contrast to the situation in 1982.

Immediately after the plots were harrowed, samples were taken from the top soil for an analysis of the aggregate structures and bulk densities. From the figure 8.22 is seen that increasing the number of harrowings from one to three times did affect the soil structure. A still more intense harrowing had a somewhat smaller effect on the soil structure. It is also seen that the fracturing was most effective in 1982, when the soil was drier.

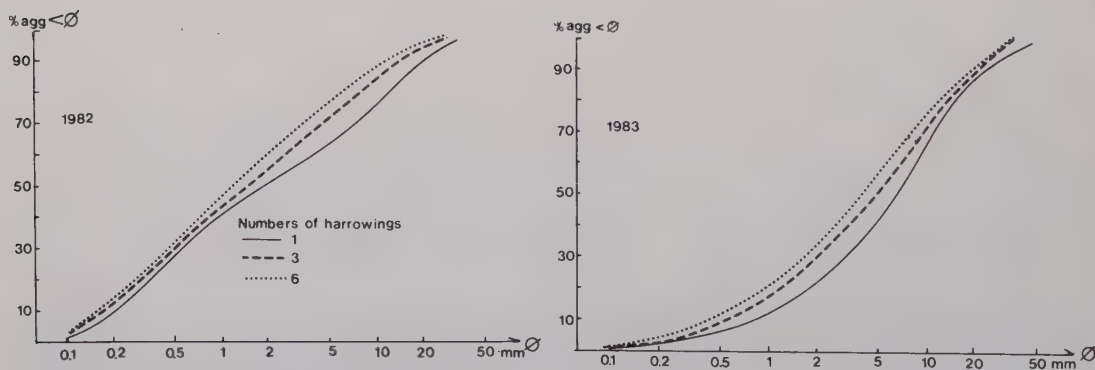


Figure 8.22. Accumulated aggregate sizes of the soils harrowed once, three times and six times, respectively. In both years two samples were taken from each plot immediately after tilling.

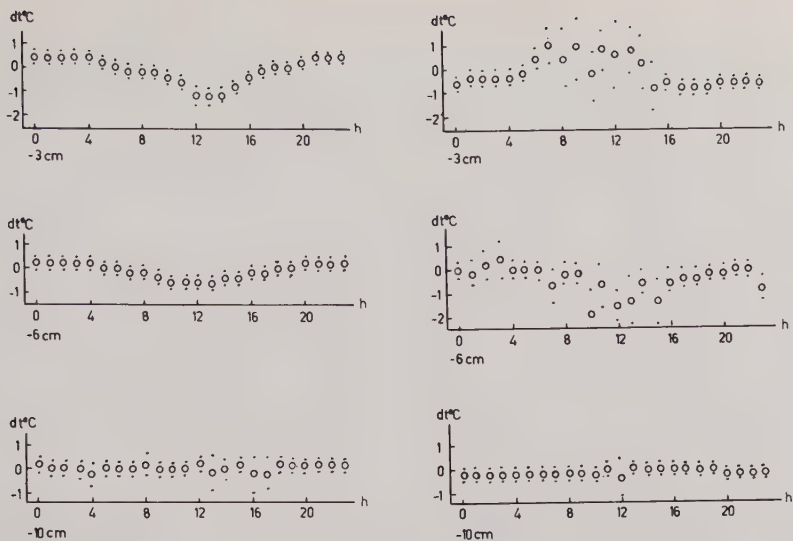


Figure 8.23. Mean hourly temperature anomalies at different depths of the plots harrowed three times (left) and six times (right) in relation to the plot harrowed only once. The 95%-confidence limits are marked. Data from the period 82.04.27-05.23.

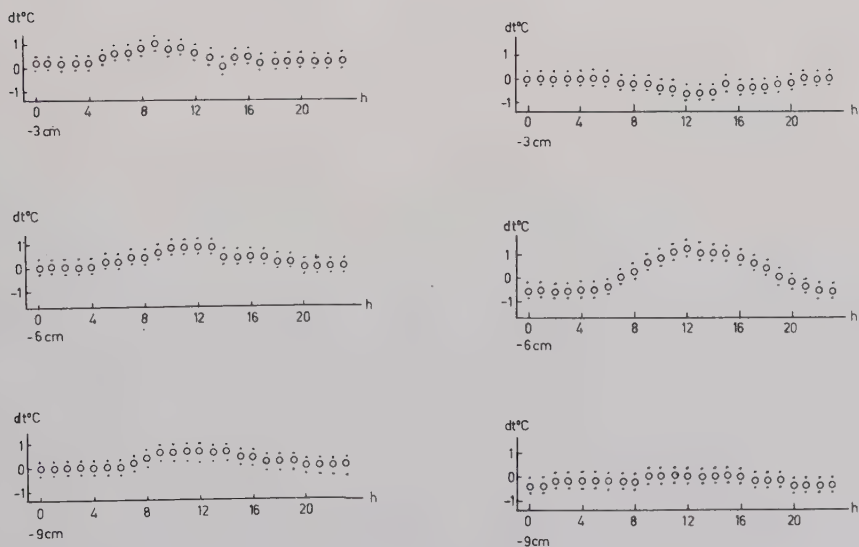


Figure 8.24. Mean hourly temperature anomalies at different depths of the plots harrowed three times (left) and six times (right) in relation to the plot harrowed only once. The 95%-confidence limits are marked. Data from the period 83.06.04-07.03.

The analyses of bulk densities showed that in 1982 this value was decreased by additional harrowings, see table 8.8. In 1983 the effect was reversed, with an increased bulk density at a more intense harrowing. These different effects could be seen as a result of the different contents of soil moisture at the time of tilling. Allmaras et al (1967) showed in an experiment that the after harrowing increase of total porosity was significantly affected by the soil moisture content at the time of the tilling. The increase was greatest with a low moisture content at the time of treatment, and the effect was reduced when the moisture content rose to the lower plastic limit (LPL). The LPL of the clayey soils he tested was between 23% and 29%. In his study, he only harrowed the soils once, and one might suspect that in a moist soil the initially harrowing will decrease the bulk density, and that the following harrowings, because of compaction from the vehicle, instead will increase the bulk density.

Due to the high moisture content at the time of tilling in 1983, the actual depth of the different treatments, both harrowing and sowing, showed a great fluctuation.

Table 8.8. Bulk density of the three soils, in 1982 and 1983. Each variable is based on data from only two samples.

Times of harrowing	1	3	6
1982	1.10	1.04	1.03
1983	1.09	1.13	1.19

8.6.2 Results and Evaluation

8.6.2.1 Emergence

The plots were sown with 5.5 germs per meter (Primahill), which at the maximum could give 46 400 plants per acre. The recorded emergence from the different plots is presented in the table 8.9.

One can see that the emergence in general was rather poor in 1983, when the soil moisture conditions were very bad at the time of harrowing and sowing. For both years a shallow depth of sowing was favourable. The effect of tilling was more pronounced at an increased depth. In 1982 the plot harrowed only once showed the best emergence; in 1983 it was the most intensely treated plot that gave the highest rate of emergence.

8.6.2.2 Temperature and Heat Conductivity Results

In the two years, the temperature measurements gave different results, see the figures 8.23-24. In 1982 the levels 3 cm and 6 cm below the surface, at the plot harrowed only once, showed a greater daily amplitude than the plot harrowed three times. At the same levels, the differences between the plots harrowed once and six times respectively, in daytime fluctuated very much, probably due to some fault with the thermocouple system or tem-

Table 8.9. Emergence, in percent of potential, at the different plots.

		Number of harrowing			Total
Depth		1	3	6	
1982	1.5	78.1	76.8	80.3	78.4
	3.0	76.8	79.0	70.2	75.3
	6.0	70.7	68.9	62.4	67.3
	Total	75.2	74.9	71.0	
1983	1.5	64.1	62.8	63.3	63.7
	3.0	62.0	57.6	61.1	60.2
	6.0	50.6	52.4	62.8	55.0
	Total	58.9	57.6	62.4	

porary malplacements of the sensor. There is, however, a tendency of a greater amplitude at -3 cm and a smaller amplitude at -6 cm, in the plot harrowed six times. However, these results should rather be omitted. At the deepest layer, -10 cm, the results from 1982 did not indicate any thermal effects of the different numbers of harrowing. Comparing the differences in temperature between the plots harrowed once and three times, one can see a decrease of the effect with increased depth, with the highest anomaly at the most surface close level.

The results from 1983 are to some extent different. This year the plot harrowed three times shows at all measured depths a greater daily amplitude, than the plot harrowed only once. At noon this plot is about 0.7°C warmer but during the nighttime the plots show equivalent temperatures. Thus, the daily mean temperature was higher in the plot harrowed three times. The plot harrowed six times shows at the depth of 3 cm a smaller daily amplitude, compared to the plot harrowed once. At the deeper layers, the amplitude was, however, higher in the more intensively harrowed soil.

In general the differences between the plots were greater during cloudless conditions than in cloudy situations.

The estimations of heat conductivities, too, gave different results for the two years. In 1982, the conductivity was decreased numerically by additional harrowings, even if the differences were not significant. This year the heat flux was also measured in the compact untilled subsoil. The conductivity was here found much greater than in the loose harrowed layers, see table 8.10. In a study by Papendick et al (1973) the heat conductivity of tilled soil was found to be much lower than that of untilled soil, 0.39 W/m°C instead of 1.16 W/m°C. In 1983 an increased number of harrowings raised the conductivity of the topsoil. These figures correspond to the results received in this study.

Evaluation

The opposite effects of intense harrowing on the heat conductivity during the two years could be a result of different soil moisture contents at the time of tilling.

Table 8.10. Estimated heat conductivity in W/mC (with 95% confidence limits), for the different plots in 1982 and 1983.

Number of harrowings	-4.5 cm, in the topsoil	
	1982	1983
1	0.46+/-0.09	0.56+/-0.06
3	0.41+/-0.05	0.94+/-0.08
6	0.33+/-0.18	1.16+/-0.10
-8.0 cm, in the subsoil		
0	1.18+/-0.27	

A moist soil which is tilled has a much higher tendency toward compaction than a drier soil (Eriksson et al 1974), see table 8.8. In turn, this will increase the conductivity (Hillel 1982, p 162, van Wijk & de Vries 1963, among others). Furthermore, in the moist soil the tilling had little effect on breaking up the aggregates (compare the graphs in figure 8.22). In 1982, when the soil was drier at the time of tilling, the treatment considerably decreased the size of the aggregates. Also the conductivity was decreased by a more intense harrowing technique which created a soil with a finer structure. This is an effect which is the opposite of the results discussed in chapter 8.2, concerning aggregate sizes.

The recorded differences in temperature are a result of the changes in thermal conductivity and thermal capacity. In 1982 the thermal capacity of the soil probably was decreased by a more intense harrowing, a consequence of the lowered bulk density (see Hillel 1982, p 162). Analogous to this, the capacity has, in 1983, instead increased, since the soil management raised the bulk density. The greater daily amplitude of temperature in 1982, especially in the surface-close layer of the plot harrowed only once, compared to the plot harrowed three times, could be a result of the positive decrease in heat capacity caused by more intense tilling.

The great standard deviation of the differences in temperature at the surface close layers between the plots harrowed once and six times, makes an evaluation of this relation very uncertain. The tendency to a greater daily amplitude in the surface-close layer of the soil harrowed six times, might be an effect of a decreased heat capacity in this looser soil.

In 1983, the statistically significant increase in thermal conductivity through additional harrowings increased the exchange of energy at the more intensively harrowed plots. As a result of this, the plot harrowed three times shows a greater daily amplitude than the plot harrowed once. Since the increase of conductivity was great, the thermal effect was noticed also at the depth 10 cm. The uppermost layer of the soil harrowed six times showed a lower daily amplitude, than the soil harrowed only once. This might be a result of both a greater heat capacity in the more compact soil and a more efficient conductivity with increased daytime losses of energy to deeper layers.

8.6.2.3 Soil Moisture and Evaporation

In 1982 measurements of soil moisture at a 4.5 cm depth showed that the plot that was harrowed only once dried the fastest, see figure 8.25. In deeper layers also the most intensively harrowed soil dried fast. The measurements of evaporation in 1983, too, showed that the soil from the plot harrowed once had the highest rate of water sorption, especially when the water content was high, see figure 8.26. This could be the same effect that was discussed concerning evaporation and different aggregate sizes in chapter 8.2. In that chapter the faster evaporation in the coarser soil was evaluated as a result of a greater rate of forced convection, which increases the release of moisture within the soil volume.

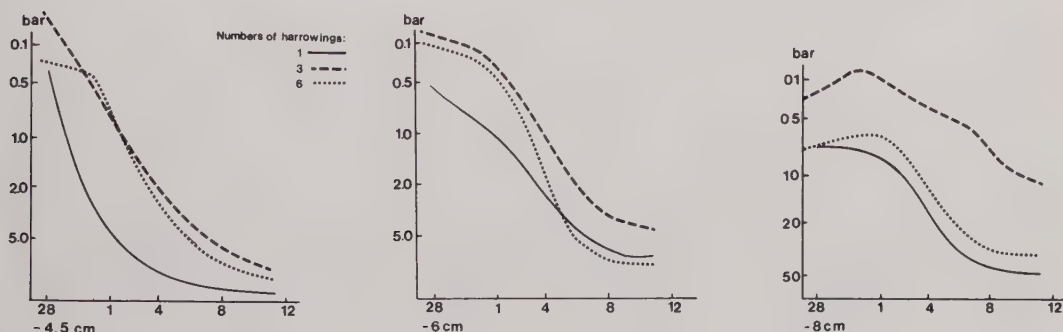


Figure 8.25. Soil moisture tension at different levels in soils harrowed once, three times and six times. Data from a period in May-June, 1982.

There has, of course, been a strong correlation between the rate of evaporation and the contemporary content of soil moisture, with faster evaporation occurring in a more moist soil. Statistical analyses have not shown that these relations vary significantly between the plots. However, the plot harrowed once showed the numerically greatest increase of the rate of evaporation by increased soil moisture. This might be a result of the fact that the wind, which raises the evaporation most when the soil is wet, has the greatest impact on a coarse soil with big pores.

Nevertheless, this does not mean that an intense tilling will save soil water, as the tilling itself causes an increase of evaporation by exposing wet soil from deeper layers to the surface.

8.6.3 Conclusions

According to the results, a more intense tilling in dry soil seems to decrease the daily temperature amplitude on the seed bottom; but if the treatment is done in wet soil the effect will be the opposite. Both effects are evaluated to be a result of changes in thermal conductivity.

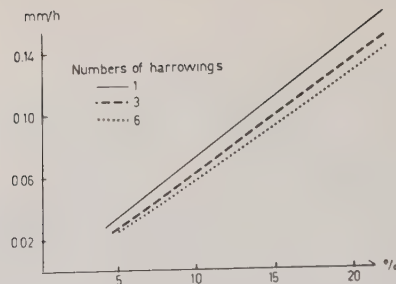


Figure 8.26. Relation between received rates of evaporation from samples of the soils harrowed once, three times and six times, and the contemporary soil water content. The differences are not statistically significant.

If the decreased anomaly at the seed bottom, after an intense tilling of dry soil, is a result of reduced heat conductivity, this will instead raise the temperature amplitude at the soil surface. By doing this, the frost risk at the surface is increased too. The more intensely harrowed soil will dry at a slower rate. This is evaluated as being both a mulching effect in the more intensely harrowed finer soils, and the effect of a greater possibility of forced convection in the more coarse soil harrowed only once. Because of the initial water losses through tilling, this effect will moderate the drying process only after a recharge of water. However, if a rain after harrowing ruins the aggregate structure, this instead reduces the improved soil moisture conditions, caused by harrowing.

8.7 EFFECTS OF SEEDBED TOPOGRAPHY

8.7.1 Introduction

8.7.1.1 Background

By modifying the surface topography of a seedbed, the microclimate of the seedbed could be affected both in the soil at the germ, and in the surface-close air around the emerging plant. An alteration of the inclination at the surface, changes the amount of incoming and absorbed radiation. Small ridges at the side of the sowing spot shade the soil and hence change the daily temperature development. Furthermore, these ridges might by reflection and emission influence the radiative climate of the bed. Ramparts also change the amount of soil covering the seed and hence affect the heat flux between the soil surface and the seed. The surface-close wind movement also is affected by small ridges and furrows; this in turn can modify the temperature and the moisture of the soil.

The study tried to describe how the seedbed topography can affect the microclimate. The climatic elements studied were soil and air temperature, wind velocity and soil moisture. Besides the study of the microclimate, emergence and yield were also examined. In the first preliminary test in 1981, the beds were built manually. Later in 1982-1984, the beds were made by sowing machines.

Similar studies were made by Mayland & Cary (1968) where they tried to minimize the sugar beet seedling damage caused by mild radiation frosts. This was done by planting the seedlings in small pockets, 7.5 cm in diameter and 5 cm deep, tilted to the

south. On average, the leaf temperature of the plants in the pockets was 2.2°C higher than the leaf temperature of plants in a conventional seedbed.

8.7.1.2 Examined Seedbeds

The preliminary studies of some manually constructed seedbeds were made in 1981. Profiles of these seedbeds are presented in figure 8.27. These seedbeds, each only a meter long, were not germinated.

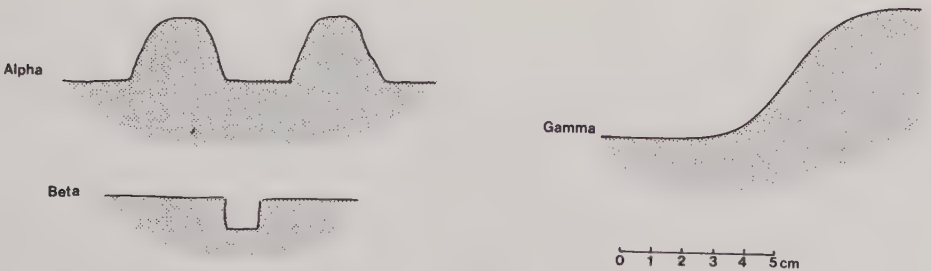


Figure 8.27. Profiles of the tested artificial seedbeds.

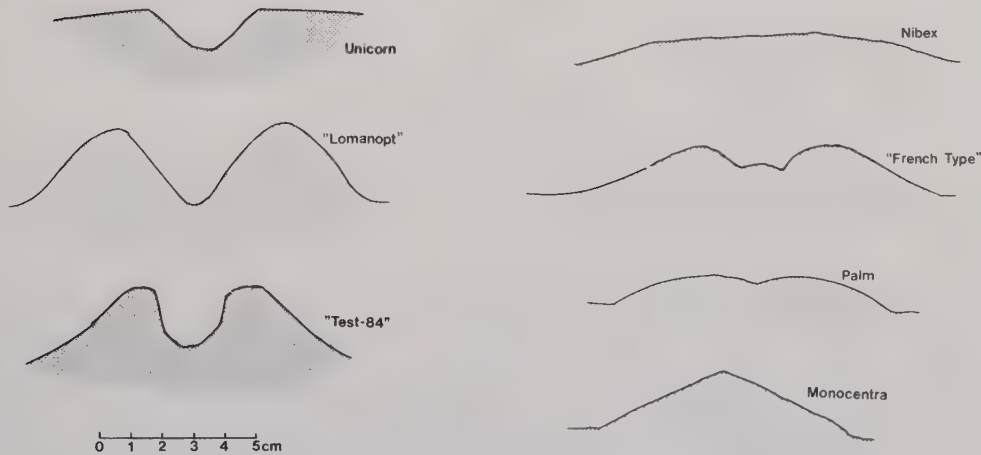


Figure 8.28. Profiles of the tested conventionally used seedbeds.

Table 8.11. Dates of sowing and measurement periods for the different years. Note that the beds in 1981 were not germinated.

1981	-	1981.06.13 - 07.31
1982	April 7	1982.04.14 - 05.15
1983	May 19	1983.05.20 - 06.15
1984	April 17	1984.04.20 - 05.21

In 1982 and 1983 seedbeds both with an east-to-west and north-to-south orientation made by the machines Monocentra, Palm, "French Type", Nibex and "Lomanopt" were tested. In 1984 the Nibex and Palm machines were changed to Unicorn (with a finger press wheel) and "Test-84". The machines "French Type", "Lomanopt" and "Test-84" are locally designed at the Agricultural Engineering Department of the Swedish Sugarbeet Company at Staffanstorp. The other machines are conventionally used in Sweden. In figure 8.28 are presented the profiles of the seedbeds made by these machines. Sowing dates and measuring periods of the different years are presented in table 8.11.

The weather during these periods is presented in chapter 1. It should, however, be mentioned here that 1983 in general was an extraordinarily wet year, both at the time of sowing and during emergence. In the other two years, the climatic situations during the studied periods were more normal.

Table 8.12. The percental emergence at the different seedbeds. EW=east-to-west orientation; NS=north-to-south orientation; T=both orientations together. At 1984, at the study of emergence, only seedbeds with a north-to-south orientation were tested. The emergence of Palm and "Test-84" were not examined this year.

	1982			1983			1984		
	EW	NS	T	EW	NS	T	EW	NS	T
Monocentra	78	81	80	87	83	85	-	77	
Palm	72	75	74	78	77	78	-	-	
"Fr Type"	70	76	73	79	83	81	-	68	
Nibex	61	64	63	78	93	86	-	71	
"Lomanopt"	78	81	80	89	92	90	-	75	
Unicorn	-	-	-	-	-	-	-	68	

8.7.1.3 The Methods

The temperature was measured with thermocouples at the seed 3 cm vertically right below the surface, and in the air 0.5 cm above the sowing spot. The soil moisture was studied only in 1982. Measurements then were made daily by using gypsum blocks. Temporarily the windflow over the seedbeds also was measured. These measurements were made with a hot wire anemometer with a probe as thick as a pencil.

When evaluating the thermal effects, temperature differences of the examined beds were examined in relation to the temperature at the same level at a plane reference surface. This difference is called the temperature anomaly of the seedbed.

8.7.1.4 Emergence

In table 8.12 is presented the emergence of the different seedbeds. In general the highest rate of emergence was found at the beds "Lomanopt" and Monocentra. This is to some extent surprising as these beds represent two contrary temperature regimes.

8.7.2 Results and Evaluation
8.7.2.1 Air Temperature

The thin thermocouples for measuring air temperature were very easily broken, and almost daily some of them had to be repaired. Because of this much data was lost, especially in 1982 and 1983, which led to an enlarged standard deviation of the received anomalies.

Artificial beds

The recorded anomalies in temperature for these beds are presented in the figure 8.29. At the bed "Gamma", the time of maximum anomaly naturally changed, depending on the aspect. The easterly facing slope had this maximum anomaly at 10.00 and the southerly at 12.00-14.00. The easterly facing slope is a little bit cooler than the plane surface in the evening because of shading. The anomalies of the westerly facing slopes show a great variation, perhaps because of sensor malfunctions. On the basis of these measurements, nothing could be verified for this bed.

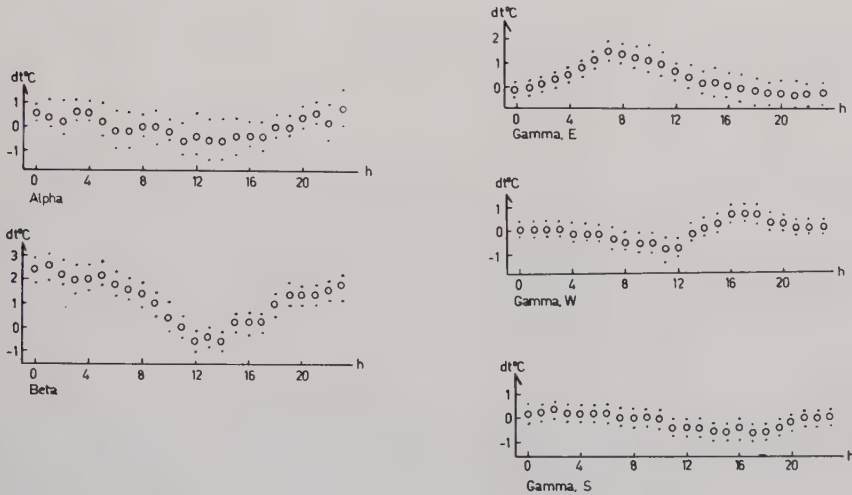


Figure 8.29. Mean hourly air temperature anomalies of the beds Alpha, Beta and Gamma (facing East, West and South). The 95%-confidence limits are marked. Data from the period 81.06.13.07.07.

In order to study the effects of wind speed on the nighttime temperature anomaly, this anomaly for clear situations at 03.00 in the morning was plotted against the contemporary wind velocity, figure 8.30. From this figure is seen that there is no anomaly in temperature at stronger wind velocities, but at lower, ($u < 1$ m/s) the anomaly was pronounced. The positive anomaly at night is caused by a decreased sky view factor; but at higher wind velocities, this anomaly will be eliminated by ventilation.

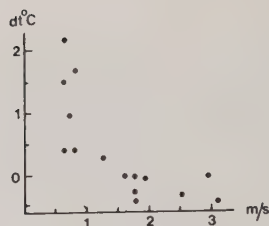


Figure 8.30. Correlation between the air temperature anomalies of the bed Gamma (facing South) at 03.00 h, and the contemporary wind velocity.

Seedbeds of tested machines

In figure 8.31 is presented examples of the anomalies of the air temperatures at the different seedbeds with a north-to-south orientation. Most of these diagrams show situations from 1984, but some diagrams with complementary situations are based on data from 1983.

In the figure is seen that in general the convex beds, Nibex, Monocentra and Palm, have affected the soil temperature only to a slight extent, perhaps because of their relatively small relief. However, in 1984, a markedly positive daytime anomaly can be noticed for the bed Monocentra. This raised anomaly can be seen as a consequence of a combination of factors the limited soil volume that has to be warmed up, and the fact that cloudless conditions, which create the greatest anomalies, were more frequent in 1984.

At the concave seedbeds (Unicorn, "Lomanopt", "French Type" and "Test-84"), the air temperature in general was higher most of time during the day; at noon, a positive anomaly of some 2°C was created. Also at nighttime, these beds were in general somewhat warmer, by about 1°C. In some beds with a north-to-south orientation, a dip in temperature is noticed in the morning and at the evening. The positive anomalies in daytime are thought to be a result of the trapped radiation and decreased losses of energy by convection, since the topography represses the surface-close wind movement. The positive anomalies of these beds at nighttime are seen as a result both of reflection from the soil walls to the enclosed air and decreased energy losses due to wind movements. The depletion of the anomaly in morning and at evening, which was noticed in these concave seedbeds with a north-to-south orientation, could be due to shading from the incoming radiation by the lateral ridges. These depletions were not found at the beds with a west-to-east orientation. No other significant differences of air temperatures, due to the east-to-west or north-to-south orientation of the beds were found.

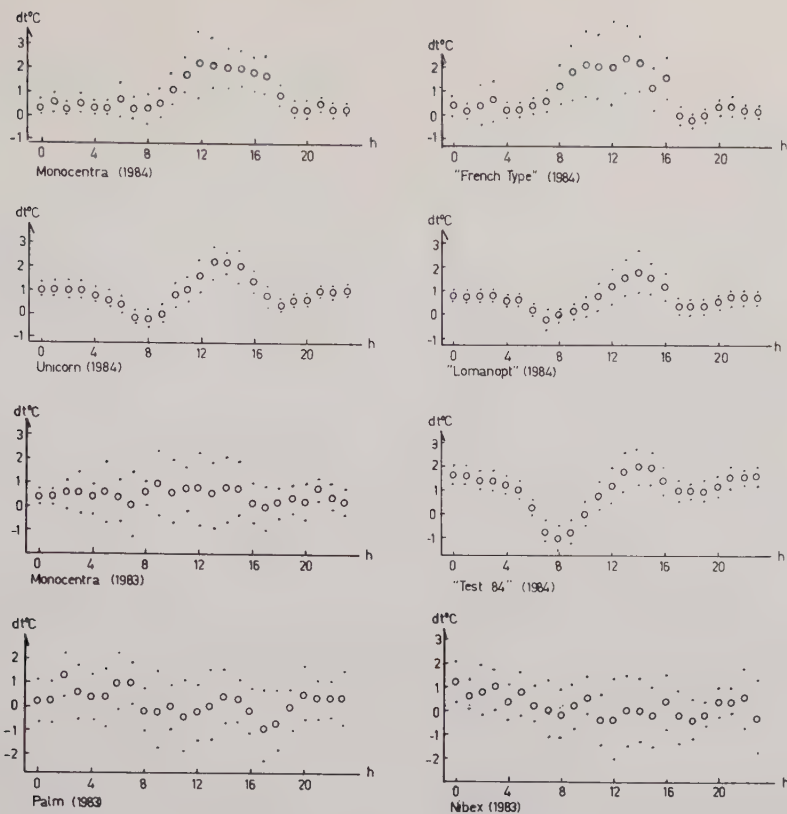


Figure 8.31. Mean hourly air temperature anomalies of the north-to-south oriented beds of the tested machines. The 95%-confidence limits are marked. Data from 1983 during the period 83.05.23-06.22 and from 1984 during the period 84.04.20-05.21.

8.7.2.2 Soil Temperature

Artificial beds

Recorded anomalies of soil temperature in the artificial beds, 3 cm below the surface, are presented in figure 8.32. From these graphs, it is seen that the seedbeds "Alpha" and "Beta" have reduced the daily amplitude of temperature, a result of more soil covering the sensor at sowing depth. This effect was strongest for "Alpha".

As in the case of the air temperature, the soil temperature of the bed "Gamma" was affected by the aspect and inclination, whereas in daytime there is a marked positive temperature anomaly for the beds facing east and west, due to better orientation of the surface which receives the incoming radiation. The differences in time, due to aspect, when the maximum anomaly is reached, is also easily perceived.

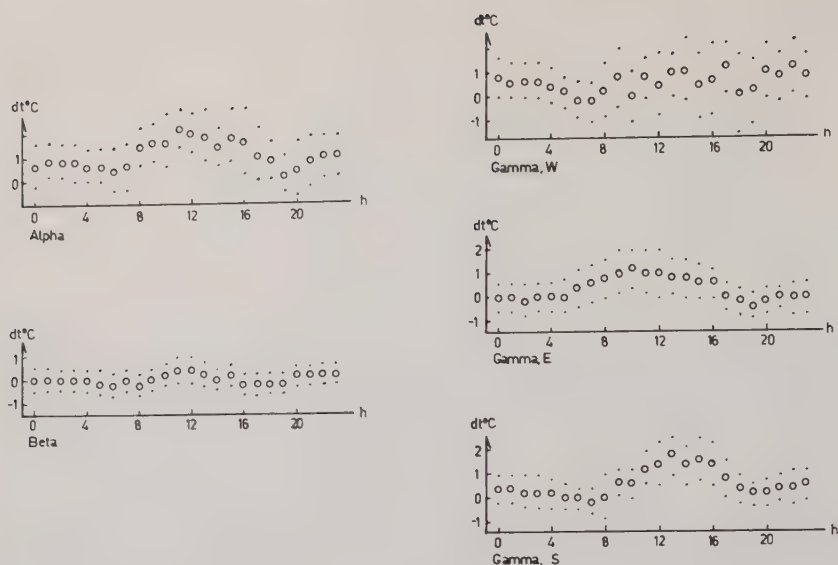


Figure 8.32. Mean hourly soil temperature anomalies, 3 cm below the surface, of the beds Alpha, Beta and Gamma (facing West, East and South). The 95%-confidence limits are marked. Data from the period 81.06.13-07.07.

Seedbeds of tested machines

Some results of the measurements of soil temperature in the seedbeds are presented in figure 8.33.

The data from 1982 shows that there was an increased daily amplitude at the convex beds Monocentra, Nibex and Palm. However, measurements from the following years have not shown this increased anomaly of these beds. The increased anomaly is probably caused by less soil covering the seed, but because of a small relief, this effect is only minor.

The effects of the concave seedbeds on the temperature at the seed were opposite the indicated effects of the convex seedbeds: the amplitude was decreased both by raised nighttime temperatures and by cooler temperatures in daytime. On average the daytime temperature was about 2°C lower and the nighttime temperature 1°C higher than the temperature at the corresponding level of the flat surface. This is evaluated as a result of the thicker soil layer covering the seed, which dampens the exchange of energy at the seed.

In 1982 the soil temperature in the seedbed "Lomanopt" was not only measured in the center of the bed, but also laterally in the ridges. The temperature effects of these ridges were the same as noticed in the bed "Gamma": a positive anomaly of the ridge facing the sun at the time of optimal inclination. The effect was smallest in the seedbed with a ridge facing to the south, see figure 8.34. This could be due to the fact that the elevation of

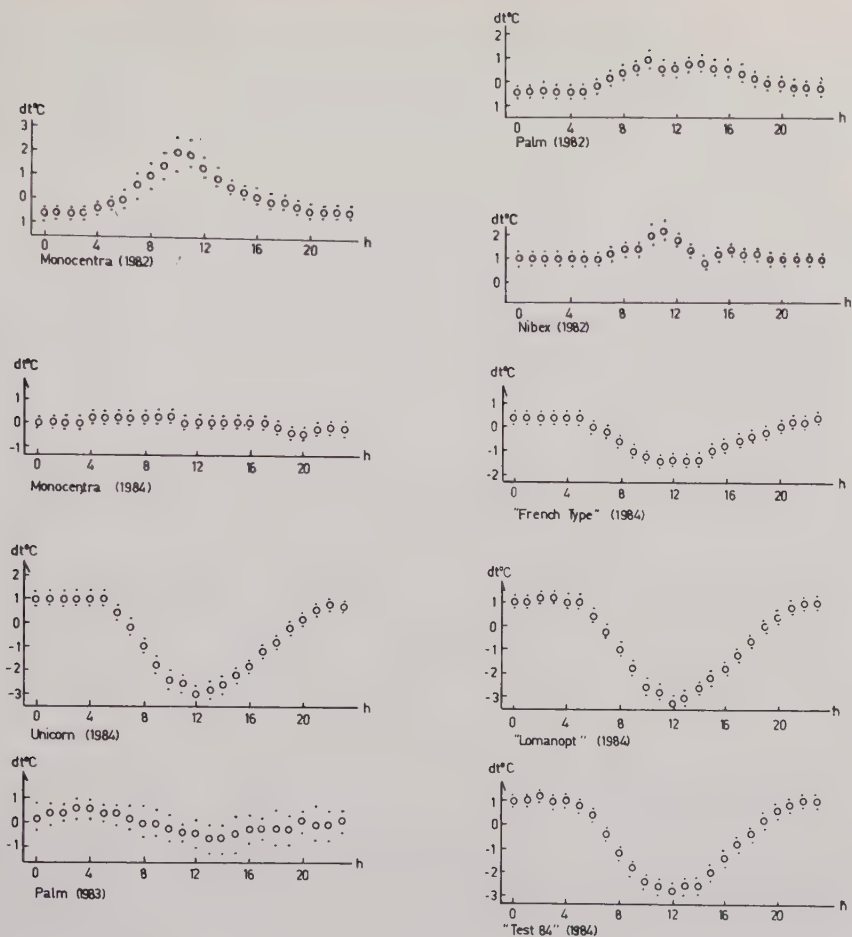


Figure 8.33. Mean hourly soil temperature anomalies, 3 cm below the surface, of the north-to-south oriented beds of the tested machines. The 95%-confidence limits are marked. Data in 1983 from the period 83.05.23-06.22 and in 1984 from the period 84.04.20-0521.

the sun at noon was too high for an optimal perpendicular inclination towards the surface of the relatively steep ridge. The differences in temperature between the easterly and westerly oriented ramparts could have a similar cause as the seedbed in reality was not symmetrical, see figure 8.36.

It should also be said that the anomalies of both air and soil temperatures generally were greater during cloudless situations. This is of importance because it is in these situations that the risk for damage caused by frost and, thus, the benefits of raised temperatures are the greatest.

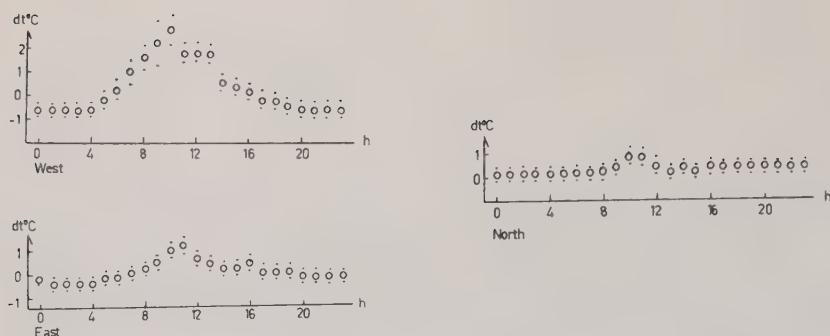


Figure 8.34. Mean hourly soil temperature anomalies in the ramparts of the bed "Lomanopt". Measurements were done in the westerly and in the easterly rampart of a bed with a north-to-south orientation (left), and in the northern rampart of a bed with a west-to-east orientation (right). The 95%-confidence limits are marked. Data from the period 82.04.14-05.15.

8.7.2.3 Soil Moisture

In 1982 the soil moisture above the seed bottom was measured with two gypsum blocks (0.5*1*3 cm in size) in each bed. The result of these measurements was not satisfying. During a period of water sorption it was seen that the differences within a seedbed sometimes are greater than the differences between two different seedbeds. For instance, on May 17, one block showed that the seedbed Palm was completely dry, whereas the other block showed that the soil at this bed was well filled with water.

The conclusion one can make from this study is that the method used does not work for this kind of experiment. The problem when estimating soil moisture from measurements by gypsum blocks, is that the blocks should have the same characteristics of water conductivity and capacity as the soil. This was not the situation when examining the very loose upper centimeters of the soil in a seedbed.

One expects, however, that a bed with an exposed convex profile will dry at the fastest rate; both because of less soil covering the seed and because of a higher exposure to the wind. Of course the process of water sorption is also affected by the hydraulic conductivity of the soil, both capillary and gas diffusion; variables that could be affected by the seeder. As this is not primarily an effect of the microtopography, it will be discussed in other chapters. The rate of drying is of course, in the long run also affected by the Buckingham effect, more thoroughly discussed in chapter 4.3.

8.7.2.4 Wind flow

In 1981, studies of the wind flow above the seedbed Monocentra and the artificial beds "Alpha" and "Beta" were made. In 1982 wind velocities were measured 0.5 cm above the tested seedbeds with wind both parallel and perpendicular to the bed. The results of the measurements are presented in table 8.13 and figure 8.35.

Table 8.13. Wind speed over the tested seedbeds, showing the situation with the bed parallel to the wind (II); the bed perpendicular to the wind (L); and the contemporary wind at a corresponding level above a flat surface (Ref). At each spot 10 readings were made. The values are presented with the 95% confidence limits. The letter "A" at Monocentra refers to a position in the trench, just beside the bed, and "B" above the ridge of the seedbed.

	II	L	Ref
1981, April 29, 15.00			
Monocentra			
A +0.5 cm	0.4+/-0.1	0.3+/-0.1	0.5+/-0.2
B +0.5 cm	0.5+/-0.1	0.8+/-0.1	0.5+/-0.2
B +2.0 cm	0.7+/-0.1	1.1+/-0.2	0.7+/-0.2
B +5.0 cm		1.2+/-0.2	
B +10.0 cm	2.9+/-0.5	2.7+/-0.2	2.8+/-0.4
+5.0 m			5.4
1981, June 21, 10.30			
Beta			
+0.5 cm	0.2+/-0.1		0.7+/-0.1
+5.0 m			1.7
1982, April 11, 11.00			
Monocentra	0.7+/-0.3	0.6+/-0.2	0.5+/-0.2
Palm	0.5+/-0.2	0.5+/-0.3	
"French Type"	0.4+/-0.2	0.5+/-0.2	
Nibex	0.5+/-0.1	0.5+/-0.2	
"Lomanopt"	0.2+/-0.1	0.4+/-0.1	

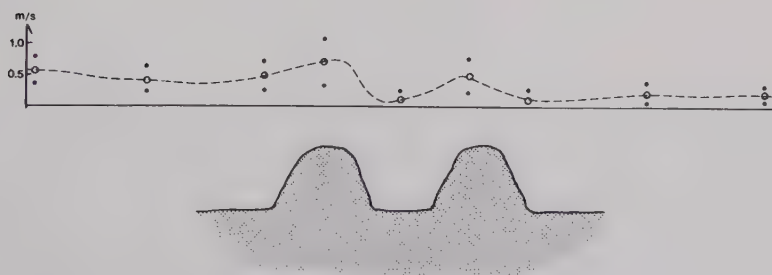


Figure 8.35. Wind flow over Alpha in June 21, 1981. The measurements were made 0.5 cm above the surface, 12 times in each position. The 95%-confidence limits are marked.

From the table 8.13 and the figure 8.35, one can observe the decrease in wind velocity over seedbeds with a marked concave profile, like "Alpha", "Beta" and "Lomanopt", and the increase in wind velocity over the seedbed with the most convex profile, Monocentra (with a wind flow perpendicular to the bed). The table also show that in case of wind parallel to the seedbed, the bed has only a very small effect on wind velocity.

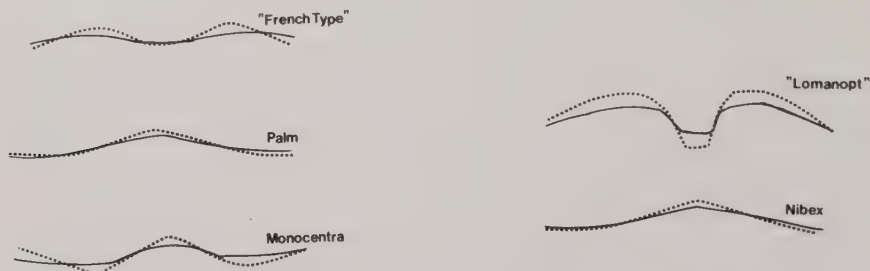


Figure 8.36. Recorded profiles of the beds tested in 1983 immediately after their construction (broken line) and two weeks later (solid line).

Linked with the wind flow is the decay of the seedbed, caused by deposition and deflation of materials. In order to study these phenomena, ten photographs were taken of each seedbed tested in 1983, immediately after sowing and two weeks later. The estimated average profile of each bed at these two occasions, are presented in figure 8.3. It is seen that the beds have collapsed to some degree, but that the main structure still is left. The decay was of course dependant upon the weather; in 1984 an intense rain in late May almost totally ruined all the beds.

8.7.3 Conclusions

The studies showed that there are possibilities to affect the temperature around the seedling, by changing the microtopography of the seedbed. However, one problem is that one often has to choose whether for instance the temperature should be raised in daytime or in nighttime, as the nighttime and daytime effects of a bed often are contradictory each other. The positive anomalies (in relation to the temperature at the same level of a flat reference surface) in daytime of seedbeds with a surface sloping towards the sun, have, however, not been combined with a negative anomaly during the night.

In general the anomalies, both positive and negative, were greater during cloudless situations than when the sky was covered with clouds. This means that when the temperature in daytime is low because of a cloud cover, an optimal micro topography of the seedbed increases the temperature only to a slight extent. If the daytime temperature is high, because of strong radiation, then this variable will not repress the growth. During this daytime

situation it is possible, though, to rise the soil temperatures several degrees by a more optimal topography. On the other hand when the temperature at nighttime is low because of a strong outgoing radiation, due to a clear sky, seedbeds with an optimal topography might raise the temperature several degrees, and by this a frost situation can be avoided. Therefore it could be better to improve the nighttime temperature by modifying the microtopography of the seedbeds, instead of raising the daytime temperatures, if a general rise in temperature is desirable.

Effects on the wind climate were also noticed. The wind velocity at concave beds, oriented perpendicularly to the wind, was decreased. A slight increase of wind velocity was noticed at the most convex bed with this orientation. No significant effects on winds parallel to the bed were noticed.

The studies have not been able to show changes in soil moisture and evaporation due to the topography, but one can suspect that the changes in temperature and wind velocity also affect these variables. The input of water by rain might, to some extent, be affected by ridges, a micro catchment around the sowing spot, but this was not observed.

8.8 EFFECTS OF PLOWLESS TILLAGE

8.8.1 Introduction

8.8.1.1 Background

Plowless tillage is a technique that recently has been given a increased attention. Some of the advantages with this technique result from the reduced passages of different vehicles. This decreases the compaction of the subsoil which is of great importance, as this part of the soil column is not loosened by harrowing. Another advantage is that the natural pore system will be maintained. This pore system is of significance for the movement of water in the soil. Finally, not unimportant for the farmer is the reduced gas consumption. The technique seems to be most useful in silty and clayey soils (Heinonen 1985, p 70 and Rydberg 1982) with a high tendency to self mulching during freeze-thaw cycles (Jerbo & Sandegren 1972 and Johansen 1977). There are also negative effects of this technique, for instance problems with weeds that are not controlled mechanically, or the decreased aeration of the soil system (Rydberg 1982).

The soil structure in a crop system of plowless tillage differs from the soil of an ordinary tillage system. This causes differences in thermal and hydrological characteristics. Also the fact that crop residues are left behind, will modify temperature, evaporation, soil moisture, and wind conditions. Finally, it should be stated that the risk of erosion by wind and sheet wash, will be greatly modified.

The aim of this study was to evaluate how a technique of plowless tillage affects the soil temperature, soil moisture content and wind conditions.

8.8.1.2 Methods

In this study, carried out in 1981, soil temperatures were measured with thermocouples at the depth 5 cm both at a plot with an ordinary crop system (plowed in the autumn and harrowed before sowing in the spring), and a plot which was neither plowed nor harrowed.

The soil moisture 3 cm, 5 cm and 10 cm below the surface was measured at the two plots by using gypsum blocks. Temporarily, wind velocity measurements were made with a hot wire anemometer.

8.8.2 Results and Evaluation

8.8.2.1 Temperature

In figure 8.37 is presented the temperature anomaly of the plot with plowless tillage in relation to the reference plot. Two effects could be noticed; the daily mean temperature was lowered 1.1°C , and the daily amplitude was decreased.

The reduced mean temperature of the untreated plot may be a result of greater evaporation, due to an increased support of water by a more effective capillary rise in the non-disturbed, continuous pore system. However, direct measurements of the evaporation were not made. The reduced daily amplitude could be caused by many phenomena. As the evaporative demand was the greatest in daytime, this caused a decreased amplitude, by means of a greater evaporative reduction of daytime temperatures than of nighttime temperatures. The greater heat capacity of the more moist and compact top soil also dampened the daily amplitude of temperature. The increased heat conductivity of the more moist and compact soil decreased the amplitude for the most surface-close layers. On the other hand, an increased heat capacity increased the temperature amplitude at deeper layers. Finally, shading the crop residues, reduced the radiative exchange of energy at the soil surface. Since the daily net radiation at this time of the year was positive, the effects of shading also reduced the daily mean temperature.

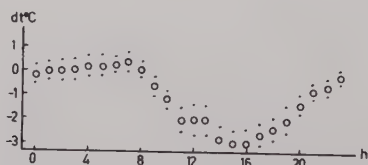


Figure 8.37. Hourly temperature anomalies 5 cm below the surface of a non-tilled plot in relation to a plot treated in a conventional way. The 95%-confidence limits are marked. Data from the period 81.04.14-05.15.

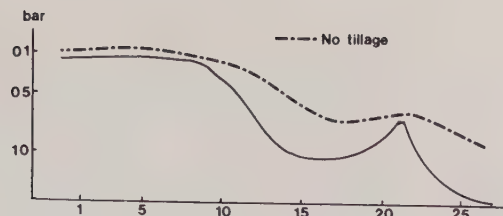


Figure 8.38. Soil moisture tension at the 5 cm depth in a non-tilled plot and in a plot with an ordinary treatment.

8.8.2.2 Soil Moisture

In figure 8.38 is seen the slower rate of water sorption at the non-tilled soil. This may be caused by a high capillary conductivity, which could effectively support the top layer with moisture, and in spite of a high actual evaporation, maintain a moist surface layer. On the other hand, the deeper layers at the non-tilled plots should dry faster. Unfortunately, measurements of soil moisture were not made at these deeper layers.

8.8.2.3 Wind flow

In figure 8.39 wind profiles are presented. The figure shows how effectively crop residues depressed the surface-close wind movements. The consequences of the depressed wind movement will be a decreased rate of evaporation and decreased evaporative cooling. However, the decreased rate of evaporation may lead to an increased total loss of water by evaporation (Hillel 1982, p 277), due to the so-called "Buckingham's effect". This phenomenon is discussed in chapter 4.3, dealing with actual evaporation.

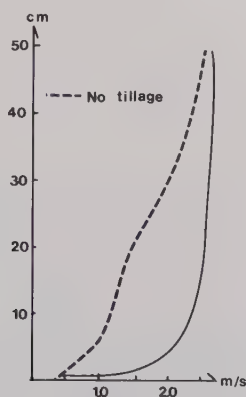


Figure 8.39. Wind velocity above a non-tilled plot with crop residues at a height of some 15 cm and above a plot treated in a conventional way.

The reduction of wind velocity will of course also affect the wind-induced erosion, and depress the risk for erosion caused by sheet wash (Morgan 1979, p 2, among others).

8.8.3 Conclusions

The study showed some climatic effects of a plowless tillage technique. The daily mean temperature and daily amplitude of temperature were lowered, probably due to effects of evaporative cooling and increased heat capacity and conductivity of the compact soils. The soil moisture content at the surface-close layers of the non-tilled plot was increased due to changed hydrological properties. Singular measurements showed that the surface-close wind velocity was reduced greatly.

When evaluating the total effect of plowless tillage on the crop production, the negative effects of decreased mean temperature and increased wear on the sowing machines must be compared to such factors as increased soil moisture at the surface, decreased wind exposure of the seedlings and decreased risk for damages by different kinds of erosion. Also other agricultural factors, such as aeration and resistance in the soil against root development, gas consumption, among others, have to be considered; consult the cited literature. As the agricultural conditions vary greatly, the benefits (if there are any) are very dependent on climate, soil and crop.

8.9 SUMMARY

The studies showed that there are great possibilities to modify the microclimate of a germ or a seedling, by creating different soil structures and using different techniques for soil management. The magnitude of the thermal effects of different treatments at the most surface-close layers, are usually within a few degrees of each other. Generally the changes in temperature were caused by a modification of the thermal properties of the soil, but also effects of evaporation and net radiation at the soil surface were of importance.

Not only the temperature, but also evaporation and soil moisture were affected by the soil structure and different techniques in soil management which modify the hydraulic properties of the soil.

In many cases, a raised daytime temperature was linked to a depressed nighttime temperature. An improved temperature condition could also be combined to a reduced soil moisture content. When this is the case, consideration has to be given to which effect is of most importance. By combining different techniques it is possible, though, to modify many variables in a positive way and thus improve the conditions for crop production.

The surface-close wind movement could be modified by the microtopography of the bed, as well as by crop residues. This affects both the evaporation and the energy balance of the bed.

Furthermore, even if a raised soil temperature usually increases the growth, this might not always increase production. It could be that this modification of the temperature only occasionally is of interest, for instance, to prevent a frost situation. This means that when evaluating the agricultural effects, one has to test different techniques for several years, before one can tell the effects on crop productivity.

Studies of this kind, which try to find ways to a deliberate modification of the crop climate, must of course be combined with studies that describe how different changes of the crop climate affects the plant, both the growth during the establishment and the final yield.

The thesis has tried to highlight three different problems dealing with agroclimatology and sugar beet cultivation:

- * To describe the micro climate of a sugar beet stand (*Beta vulgaris*, L.), and to evaluate how the microclimate of the beet stand is a function of an interaction between the stand itself and the weather.
- * To evaluate how the climate during the establishment might affect the plant growth during this period and the yield at harvest.
- * To examine the possibilities for a deliberate modification of the crop climate in order to improve the growing conditions.

The work has also developed techniques in crop climatological studies. A method for interpolating the daily temperature development on the basis of the daily extremes is presented in chapter 3. In chapter 4 is presented a simple micro-lysimeter for determining the actual evaporation from a soil.

The field studies were carried out at an experimental field of the Swedish Sugar Beet Company, Agricultural Engineering Department, Research and Development, located in the southernmost part of Sweden. In chapter 1 the climate of this region (Köppen type Cfb), as well as the environment in general, is described more thoroughly.

Most recordings of the climatic variables were made automatically by a 82-channel data acquisition system. The variables measured by this system were temperature, air humidity, wind velocity, net radiation and heat flux in the soil. Some separate instruments were used for other variables, such as evaporation (potential and actual), soil moisture content and precipitation.

Generally, each chapter is independent, dealing with circumscribed problems and can therefore be read separately.

A presentation of the microclimate in general (temperature, moisture and wind) is given in the chapters 3-5. Chapter 3 treats the temperature climate at a bare soil surface and a growing beet stand. Different analyses have quantified how the temperature is affected by other meteorological variables.

The rate of water sorption and resorption under different weather conditions is evaluated in chapter 4. At deeper layers under the beet stand the sorption was increased by the transpiration. On the other hand the drying at the surface-close layers was reduced at the beet stand by shading effects and repressed ventilation. The reduced ventilation, together with the transpiration, increased the relative humidity in the air within and close to the stand. Besides the delay due to the intercept, the water resorption at rain was faster at the more loose soil protected by the beet stand, than at the compact unprotected bare soil.

In chapter 5 the surface-close wind velocity is analysed. Here is presented how the wind profile gradually was modified by the growing stand, the zero plane was raised and the roughness length was increased. The stand structure's impact on ventilation and erosion is discussed, too.

Results from measurements of the extremely plant-close temperature and wind climates are presented in chapter 6. On bright days the surface temperatures of beet leaves were raised by some degrees (in relation to the temperature of the ambient air). Measurements of the leaf temperature under semispherical water droplets showed on bright days an even greater temperature rise. This enhanced temperature rise was caused by the concentration of the rays due to refraction in the droplets.

In the very near vicinity of the plants occurred great horizontal gradients of the surface-close soil temperature. These gradients were due to shading effects.

Singular plants affect the wind velocity only for a very short distance; already within some centimeters the effects are usually almost totally absent. The reduction in wind velocity was found to be most intense at the lee side of the plant, but was seen also at the wind-ward side.

Some results presented in chapter 7, indicate the effect of the micro-climate on the plant development. The number of days needed for emergence was reduced and the percental emergence was raised by an increased temperature before emergence. The emergence was delayed by dry spells. However, these dry periods did only slightly affect the percental emergence.

During the first period after the plant emergence, the shoot development showed an optimum response to temperature. An optimum response was indicated also for soil moisture content.

In the different years, both positive and negative relations were recorded between the temperature during the establishment and the final yield at harvest, measured as root weight per plant. The contradictory results could be caused by the fact that a cold period in springtime stimulates the root growth. This might be advantageous later in the year, if soil moisture or nutrient content limits the development. The recorded negative impact of temperature could also be a result of the reduced percental emergence at cooler periods. The surviving plants then could grow bigger as the competition was reduced.

Furthermore, an optimum response of the root yield to soil moisture content was indicated during the establishment.

In chapter 8 is evaluated how soil conditions (aggregate structure, compaction, moisture content and stone) and soil management (harrowing, the use of different seeders and ploughless tillage) affect the micro-climate in the upper soil layers as well as in the air just above the surface. The results show that there are possibilities to modify the temperature climate, the soil moisture and evaporation processes, and the wind velocity by using different techniques of soil management.

By modifying the thermal properties of the soil, the temperature

at the emerging plants can be changed; day or nighttime temperatures as well as the amplitude may be raised or lowered. The evaporation process and soil moisture content, too, are affected by the soil structure. In the chapter is shown how an alteration of the hydraulic conductivity of the soil affects the sorption. The impact of the soil structure on evaporation differs at the different stages of evaporation. Furthermore, it is shown that the soil moisture content as well as the evaporation, in turn, act on the temperature by effecting the thermal properties of the soils and the evaporative cooling.

Finally in this chapter is shown how the surface-close wind movement is modified by the micro-topography of the seed beds and by crop residues.

REFERENCES

Abbreviations:

Agron. J.	Agronomy Journal
SLU	Sveriges Lantbruksuniversitet, Swedish University of Agricultural Sciences, Uppsala
Quart. J. R. Met. Soc.	Quarterly Journal of the Royal Meteorological Society, London
Soil Sci. of Amer., J.	Soil Science Society of America, Journal
Soil Sci. of Amer., Proc.	Soil Science Society of America, Proceedings

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